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Final
Report

December 1972

Preliminary Design Study for an Atmospheric Science Facility

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National Aeronautics and Space Administration
Science and Applications Directorate
Manned Spacecraft Center
Houston, Texas

MARTIN MARIETTA

194

MCR-72-322

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PRELIMINARY DESIGN STUDY FOR AN ATMOSPHERIC SCIENCE FACILITY

Prepared by:

Dr. R. Hutchison

Approved

B. Hartel
Program Manager

MARTIN MARIETTA CORPORATION
P. O. Box 179
Denver, Colorado 80201

FOREWORD

This document has been prepared and submitted in accordance with Paragraphs 3.2 and 3.6 of Exhibit "A" and Paragraph 2.5 of Exhibit "B" to, and Article VII of MSC Contract NAS9-12255.

In accordance with the requirements of Article XVI of the subject contract, this report uses the International System of Units as the preferred primary system. The units used are those specified in NASA SP-7012, *The International System of Units*, except in the areas of radiance and wavelength. As permitted by Article XVI and by SP-7012, expressions in these areas are in both SI units and customary units (Rayleighs, degrees and Angstroms). The use of other units in the ultraviolet region would impair communication and reduce the usefulness of this report to the primary recipients.

ACKNOWLEDGMENTS

The following personnel have made significant contributions to the preparation of this report:

W. Bloomquist
N. Ganiaris
R. Hutchison
E. Mangold
W. Owen
L. Pownall
K. Worman

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I. INTRODUCTION

This document is the final report on the activities and results of the Atmospheric Science Facility (ASF) Preliminary Design Study (Contract NAS9-12255). The objectives of this study were to define the scientific objectives, range of experiment types, and the preliminary instrument design requirements for a reusable, manned, general-purpose optical research facility for the study of the Earth's atmosphere from a Space Shuttle orbital vehicle.

The study consisted of five principal tasks. Task I involved the definition of science objectives, experiment types, and experimental design requirements. Tasks II and III were preliminary design tasks for instruments and for collecting optics with associated pointing and control, respectively. In Task IV, results of the study were presented to a conference of participating scientists at NASA-MSC in October 1972, and the results of that conference were incorporated into an updated definition of objectives and preliminary designs. Task V involved the initiation of long-lead development phase activity for the instruments most likely to be contained in the ASF.

The material in the report basically follows the chronology of the study; however, Task IV results are reflected throughout the document in the sections to which they apply. Following the introduction (Chapter I), Chapter II describes the efforts of Task I, science objectives, etc. Chapters III and IV present the results of Tasks II and III, in the form of an implementation approach, and preliminary performance requirements to be placed on instrumentation, pointing and control. Chapter V contains a number of supporting analyses that were performed during the study, and studies of related topics are presented in Chapter VI. Chapter VII summarizes and reviews the major conclusions derived in the study.

The report contains two appendixes--Appendix A presents further details on the preliminary designs of instruments, pointing and control, and Appendix B discusses a number of concepts and approaches investigated and abandoned during the course of the study.

A. BACKGROUND

Studies of the emission and scattering from the atmosphere, of the solar flux impinging on the Earth, and of the extinction of this radiation at sunrise and sunset, have been made in the entire spectral region from the extreme ultraviolet to the far-infrared. These studies have been made by many observers using balloon, rocket probe, and manned and unmanned orbital platforms, and the data obtained have led to a vast improvement in our knowledge of the basic processes that control both the Earth's atmosphere, from the ground to several Earth radii in altitude, and man's environment.

Manned orbital vehicles offer an excellent platform for such studies. It is felt that the idea of experimenters orbiting their individual spectrometers must give way to the facility concept, in which general-purpose instruments are housed in a single facility. This concept could open up space science to those scientists whose institutions or countries do not have the resources to mount a full-scale rocket probe or satellite program.

The interest of NASA-MSC in such a facility concept began in early 1970, when Dr. Robert D. Hudson and Dr. Andrew E. Potter proposed the concept of a manned space laboratory for performing research in the field of atmospheric physics. They recommended a general-purpose spectrometric facility consisting of one or more telescopes and several spectrometers to cover the wavelength interval from ultraviolet to far-infrared. Conceptual studies, carried out at NASA's Manned Spacecraft Center in FY '70 have shown that such a facility concept is feasible. In September 1970, a meeting was held at NASA-MSC for more than 40 scientists (representing universities, industry, and other government agencies) to establish some scientific goals for the project and to provide some initial guidance on the facility design. The facility concept received strong support from the participants at that conference.

Table I-1 presents a complete list of scientists contacted during the Task I study. The column headings follow the chronology of the task and indicate the level of involvement of each individual.

Table I-1 Atmospheric Science Facility Participants		INVITED TO 1970 ASF SCI.-OBJ. CONFERENCE (DID NOT ATTEND*)	COMMENTED ON PRELIMINARY CONFERENCE TRANSCRIPT	RECEIVED JANUARY 1972 MAILING (4 or 5 DOCUMENTS)	DECLINED TO PARTICIPATE	RESPONDED TO QUESTIONNAIRE	SUGGESTED ADDITIONAL SCIENTIST CONTACTS	RESPONDED FOR OTHER PERSONS	RECEIVED PRELIMINARY BASELINE SUMMARY	COMMENTED ON PRELIMINARY BASELINE SUMMARY	RECEIVED FINAL BASELINE SUMMARY	COMMENTED ON FINAL BASELINE SUMMARY	RECEIVED PROGRESS SUMMARY AND CONFERENCE INVITATION	ATTENDED 1972 ASF PRELIMINARY DESIGN CONFERENCE
AIKIN, A.C.	GODDARD SPACE FLIGHT CENTER CODE 615.4 GREENBELT, MARYLAND 20771	YES		4					X		X		X	
ALISHOUSE, JOHN	NOAA - NESS FOB4 ROOM 0118 SUITLAND, MARYLAND 20233													X
BAKER, DORAN (801) 752-4100	UTAH STATE UNIVERSITY LOGAN, UTAH 84321	YES		4		X	CLAYTON WYATT	MEGILL CLARK	X		X		X	
BARTH, C.A. (303) 443-7502	LABORATORY FOR ATMOSPHERIC AND SPACE PHYSICS UNIVERSITY OF COLORADO BOULDER, COLORADO 80302	YES*		4					X		X		X	1
BARTMAN, F.L. (313) 764-7210	UNIVERSITY OF MICHIGAN AEROSPACE ENGINEERING HIGH ALTITUDE ENGINEERING LAB RESEARCH ACTIVITIES BUILDING ANN ARBOR, MICHIGAN 48105	NO		5		X	NASA NOAA EPA		X		X		X	
BATES, D.R.	SCHOOL OF PHYSICS QUEENS UNIVERSITY BELFAST, NORTHERN IRELAND	NO		5					X					
BEER, REINHARD	183B/353 JET PROPULSION LABORATORY LUNAR AND PLANETARY SCIENCES SECTION PASEDENA, CALIFORNIA 91360	NO		5					X		X		X	
BIRNBAUM, G. (805) 498-4545	D/002 A10 1049 CAMINO DOS RIOS NORTH AMERICAN AVIATION SCIENCE CENTER THOUSAND OAKS, CALIFORNIA 91360	YES	X	4		X			X		X		X	
BLAMONT, J.E., PROF.	SCIENTIFIC DIRECTOR CNES 129 RUE DE L'UNIVERSITE 75-PARIS 7 FRANCE	NO		5					X					
BOWHILL, S.A. (217) 333-4150	DEPARTMENT OF ELECTRICAL ENGINEERING UNIVERSITY OF ILLINOIS URBANA, ILLINOIS 61801	NO		5					X		X		X	
BOWYER, C.S. (415) 642-1665	SPACE SCIENCES LABORATORY UNIVERSITY OF CALIFORNIA BERKELEY, CALIFORNIA 94720	YES		4		X	ITALIAN GROUP		X	X	X		X	
BRADBURY, JAMES	LOCKHEED MISSILES AND SPACE CO. RESEARCH LABORATORIES 3251 HANOVER STREET PALO ALTO, CALIFORNIA 94303	NO		4					X		X		X	
BRANDES, E.A. (405) 329-0388	NATIONAL SEVERE STORMS LABORATORY 1616 HALLEY AVENUE NORMAN, OKLAHOMA 73069	NO				X		KESSLER	X		X			

Note: 1x, 2x etc. indicates person attending conference representing 1, 2 etc.

Table I-1 (continued)

Name	Address	INVITED TO 1970 ASF SCI.-OBJ. CONFERENCE (DID NOT ATTEND*)	COMMENTED ON PRELIMINARY CONFERENCE TRANSCRIPT	RECEIVED JANUARY 1972 MAILING (4 or 5 DOCUMENTS)	DECLINED TO PARTICIPATED	RESPONDED TO QUESTIONNAIRE	SUGGESTED ADDITIONAL SCIENTIST CONTACTS	RESPONDED FOR OTHER PERSONS	RECEIVED PRELIMINARY BASELINE SUMMARY	COMMENTED ON PRELIMINARY BASELINE SUMMARY	RECEIVED FINAL BASELINE SUMMARY	COMMENTED ON FINAL BASELINE SUMMARY	RECEIVED PROGRESS SUMMARY AND CONFERENCE INVITATION	ATTENDED 1972 ASF PRELIMINARY DESIGN CONFERENCE
BURROUGHS, W.J.	MINISTRY OF TECHNOLOGY NATIONAL PHYSICAL LABORATORY TEDDINGTON, MIDDLESEX ENGLAND	NO		5					X					
BURTON, VON. L.	PD-DO-PA NASA MSFC HUNTSVILLE, ALABAMA 35812													X
CADLE, RICHARD D.	NCAR P.O. BOX 1470 BOULDER, COLORADO 80302	NO		5					X		X			
CAIRNS, RONALD B. (415) 321-3180	4103 MIDDLEFIELD ROAD PALO ALTO, CALIFORNIA 94303	YES		4		X			X		X		X	
CARLSON, ROBERT	DEPARTMENT OF PHYSICS UNIVERSITY OF SOUTHERN CALIFORNIA LOS ANGELES, CALIFORNIA 90007	YES		4					X		X			
CHAMBERLAIN, J.W. (713) 488-5200	DIRECTOR LUNAR SCIENCE INSTITUTE 3303 NASA ROAD 1 HOUSTON, TEXAS 77058	NO		5					X		X		X	X
CHARLSON, ROBERT	UNIVERSITY OF WASHINGTON SEATTLE, WASHINGTON 98105	NO		5		X			X		X		X	
CHASE, ROLAND H.	CODE SG, RM. F5034 NASA HEADQUARTERS WASHINGTON, D.C. 20546	NO		5					X		X		X	
CHUBB, T.A. (202) 767-2000	U.S. NAVAL RESEARCH LABORATORY WASHINGTON, D.C. 20390	NO		5					X		X			
CLARK, KENNETH C. (206) 543-5868	DEPARTMENT OF PHYSICS UNIVERSITY OF WASHINGTON SEATTLE, WASHINGTON 98124	NO		5					X		X			
COLTHARP, R.N.	MAIL CODE TF3 MANNED SPACECRAFT CENTER HOUSTON, TEXAS 77058	NO		4					X		X			X
CONNES, P.	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE LABORATOIRE AIME COTTON BELLVUE, HAUTE-DE-SEINE FRANCE	NO		5					X					
CONTZEN, JEAN PIERRE	INGENIEUR CIVIL A.I.BR. MANAGER, TELECOMMUNICATIONS MISSION DIRECTORATE OF PROGRAMMES & PLANNING EUROPEAN SPACE RESEARCH ORGANIZATION (ESRO) 114, AVE. DE NEUILLY 92-NEUILLY-SUR-SEINE FRANCE	NO		5							X			
COULSON, KINSEL	CO-CHAIRMAN U.S.A.R.W. GROUP COLLEGE OF AGRICULTURAL ENGINEERING DAVIS, CALIFORNIA 95616	NO							X		X			

Table I-1 (continued)

Name	Address	INVITED TO 1970 ASF SCI.-OBJ. CONFERENCE (DID NOT ATTEND*)	COMMENTED ON PRELIMINARY CONFERENCE TRANSCRIPTS	RECEIVED JANUARY 1972 MAILING (4 or 5 DOCUMENTS)	DECLINED TO PARTICIPATE	RESPONDED TO QUESTIONNAIRE	SUGGESTED ADDITIONAL SCIENTIST CONTACTS	RESPONDED FOR OTHER PERSONS	RECEIVED PRELIMINARY BASELINE SUMMARY	COMMENTED ON PRELIMINARY BASELINE SUMMARY	RECEIVED FINAL BASELINE SUMMARY	COMMENTED ON FINAL BASELINE SUMMARY	RECEIVED PROGRESS SUMMARY AND CONFERENCE INVITATION	ATTENDED 1972 ASF PRELIMINARY DESIGN CONFERENCE
DALGARNO, A. (617) 495-4721	HARVARD COLLEGE OBSERVATORY CAMBRIDGE, MASSACHUSETTS 02138	YES		4		X			X		X		X	
DA ROSA, AVIDO V. (415) 321-3672	RADIO SCIENCE LAB STANFORD UNIVERSITY PALO ALTO, CALIFORNIA 94305	NO		5					X		X			
DELUSI, J.	NCAR P.O. BOX 1470 BOULDER, COLORADO 80302	NO							X		X			
DIEMINGER, W.	DIRECTOR MAX-PLANCK-INSTITUT FUR AERONOMIE 3411 LINDAU UBER NORTHEIM/HANN POSTFACH 20 FEDERAL REPUBLIC OF GERMANY	NO		5					X					
DIRMHIRN, INGE (801) 752-4100	UTAH STATE UNIVERSITY LOGAN, UTAH 84321	NO		5					X		X			
DONAHUE, T.M. (412) 621-7386 (617) 495-4359 (FOR 1 YEAR)	DEPARTMENT OF PHYSICS UNIVERSITY OF PITTSBURGH PITTSBURGH, PENNSYLVANIA 15213	YES*		4					X		X		X	
DONN, B.D.	GODDARD SPACE FLIGHT CENTER CODE 616 GREENBELT, MARYLAND 20771	NO		5					X		X		X	
DUBIN, MAURICE	NASA HEADQUARTERS CODE SG WASHINGTON, D.C. 20546	YES*		4					X		X		X	
DUNKELMAN, LAWRENCE	GODDARD SPACE FLIGHT CENTER CODE 613 GREENBELT, MARYLAND 20771	YES		4					X		X		X	
EVANS, J.E. (415) 324-3311	LOCKHEED MISSILES AND SPACE CO. RESEARCH LABORATORIES 3251 HANOVER STREET PALO ALTO, CALIFORNIA 94303	YES		4					X		X		X	X
EVANS, J.V.	LINCOLN LABORATORY MASSACHUSETTS INSTUTE OF TECHNOLOGY CAMBRIDGE, MASSACHUSETTS 02139	NO		5	X				NO					
EVANS, W.F.J.	UNIVERSITY OF SASKATCHEWAN INSTITUTE FOR SPACE AND ATMOSPHERIC STUDIES PHYSICS DEPARTMENT SASKATOON, SASKATCHEWAN CANADA	NO		5					X				X	
FARMER, C.B.	CODE 183-301 JET PROPULSION LABORATORY LUNAR AND PLANETARY SCIENCES SECTION PASEDENA, CALIFORNIA 91103	YES		4		X	EPA DOT	TOTH	X		X		X	
FASTIE, W.G. (301) 366-3300	THE JOHNS HOPKINS UNIVERSITY BALTIMORE, MARYLAND 21218	YES		4					X		X		X	

Table I-1 (continued)		INVITED TO 1970 ASF SCI.-OBJ. CONFERENCE (DID NOT ATTEND*)	COMMENTED ON PRELIMINARY CONFERENCE TRANSCRIPT	RECEIVED JANUARY 1972 MAILING (4 or 5 DOCUMENTS)	DECLINED TO PARTICIPATE	RESPONDED TO QUESTIONNAIRE	SUGGESTED ADDITIONAL SCIENTIST CONTACTS	RESPONDED FOR OTHER PERSONS	RECEIVED PRELIMINARY BASELINE SUMMARY	COMMENTED ON PRELIMINARY BASELINE SUMMARY	RECEIVED FINAL BASELINE SUMMARY	COMMENTED ON FINAL BASELINE SUMMARY	RECEIVED PROGRESS SUMMARY AND CONFERENCE INVITATION	ATTENDED 1972 ASF PRELIMINARY DESIGN CONFERENCE
FELDMAN, PAUL (310) 366-3300	THE JOHNS HOPKINS UNIVERSITY BALTIMORE, MARYLAND 21218	YES		4					X		X		X	
FENN, ROBERT (617) 861-3181	A.F.C.R.L. L.G. HANSCOM FIELD ATMOSPHERIC OPTICS BRANCH BEDFORD, MASSACHUSETTS 01730	NO		5	X				NO					
FEW, ARTHUR A.	RICE UNIVERSITY 6100 S. MAIN STREET HOUSTON, TEXAS 77001	YES		4		X		STEBBINGS	X		X		X	X
FOGLE, BENSON	NCAR BOX 1470 BOULDER, COLORADO 80302	NO		5					X		X			
FRITZ, S.	CHIEF SPACE SCIENTIST NOAA-NATIONAL ENVIRONMENTAL SATELLITE SERVICE FOB #4 SUITLAND, MARYLAND 20233	NO				X		D.S. JOHNSON	X		X		X	
FURUKAWA, PAUL M.	NCAR P.O. BOX 1470 BOULDER, COLORADO 80302	NO							X		X			
GALEJS, N.	9326 EDMONSTON ROAD GREENBELT, MARYLAND 20770	NO		5					X		X			
GARING, JOHN (617) 861-2951	A.F.C.R.L. L.G. HANSCOM FIELD BEDFORD, MASSACHUSETTS 01730	NO		5					X		X			
GEBBIE, H.A. (303) 443-6919	UNIVERSITY OF COLORADO BOULDER, COLORADO 80302	YES*		4					X		X		X	
GILLE, JOHN C. (303) 494-5151 (x 351)	NCAR P.O. BOX 1470 BOULDER, COLORADO 80302	NO		5					X		X		X	X
GRAMS, G.W.	NCAR P.O. BOX 1470 BOULDER, COLORADO 80302	NO		5					X		X			
GRAY, CARLTON R.	DL7-236 THE CHARLES STARK DRAPER LABORATORY 68 ALBANY STREET CAMBRIDGE, MASSACHUSETTS 02139	NO							X		X		X	2
GREEN, A.E.S. (904) 392-2001	DEPARTMENT OF PHYSICS UNIVERSITY OF FLORIDA GAINESVILLE, FLORIDA 32601	YES	X	4					X		X		X	
HANEL, R.A.	GODDARD SPACE FLIGHT CENTER CODE 620 GREENBELT, MARYLAND 20771	YES		4					X		X		X	
HANSON, W.B.	UNIVERSITY OF TEXAS AT DALLAS P.O. BOX 30365 DALLAS, TEXAS 75230	YES*		4		X			X		X		X	

Table I-1 (continued)

Name	Address	INVITED TO 1970 ASF SCI.-OBJ. CONFERENCE (DID NOT ATTEND*)	COMMENTED ON PRELIMINARY CONFERENCE TRANSCRIPT	RECEIVED JANUARY 1972 MAILING (4 or 5 DOCUMENTS)	DECLINED TO PARTICIPATE	RESPONDED TO QUESTIONNAIRE	SUGGESTED ADDITIONAL SCIENTIST CONTACTS	RESPONDED FOR OTHER PERSONS	RECEIVED PRELIMINARY BASELINE SUMMARY	COMMENTED ON PRELIMINARY BASELINE SUMMARY	RECEIVED FINAL BASELINE SUMMARY	COMMENTED ON FINAL BASELINE SUMMARY	RECEIVED PROGRESS SUMMARY AND CONFERENCE INVITATION	ATTENDED 1972 ASF PRELIMINARY DESIGN CONFERENCE
HANST, P.L.	BRANCH CHIEF ATMOSPHERIC CHEMISTRY & PHYSICS ENVIRONMENTAL PROTECTION AGENCY RESEARCH TRIANGLE PARK NORTH CAROLINA 27711	NO							X		X			
HARRIES, J.E.	MINISTRY OF TECHNOLOGY NATIONAL PHYSICAL LABORATORY TEDDINGTON, MIDDLESEX ENGLAND	NO		5					X					
HEATH, D.F.	GODDARD SPACE FLIGHT CENTER CODE 622 GREENBELT, MARYLAND 20771	YES		4					X		X		X	X
HERZBERG, DR.G	DISTINGUISHED RESEARCH SCIENTIST NATIONAL RESEARCH COUNCIL OF CANADA 100 SUSSEX DRIVE OTTAWA K1A 0S1, CANADA	NO		5									X	
HINTEREGGER, H.E. (617) 861-3310	AIR FORCE CAMBRIDGE RESEARCH LAB L.G. HANSCOM FIELD BEDFORD, MASSACHUSETTS 01730	YES		4					X		X		X	X
HOCH, R.J. (509) 936-2383 OBS. 942-7136	BATTELLE NORTHWEST ROOM 1325, MATH BUILDING P.O. BOX 999 RICHLAND, WASHINGTON 99352	NO		5		X	BEARD U. OF KANSAS		X		X		X	
HODGES, R. RICHARD	UNIVERSITY OF TEXAS P.O. BOX 30365 DALLAS, TEXAS 75230													X
HOFFMAN, JOHN	UNIVERSITY OF TEXAS AT DALLAS BOX 30365 DALLAS, TEXAS 75230	NO		5		X			X		X		X	3
HOSIE, J.F.	SCIENCE RESEARCH COUNCIL STATE HOUSE, HIGH HOLBORN LONDON WC1R 4TA ENGLAND	NO		5					X					
HOUGHTON, J.T.	CLARENDON LABORATORY OXFORD UNIVERSITY OXI 3PU ENGLAND	NO		5					X					
HUDSON, R.D. (713) 483-4981	MAIL CODE TA, BLDG. 2, RM 861 NASA MANNED SPACECRAFT CENTER HOUSTON, TEXAS 77058	CHAIR	X	4					X		X		X	X
HUNTRESS, W.T.	MAIL CODE 183-301 JET PROPULSION LABORATORY PASADENA, CALIFORNIA 91103	YES		4					X		X		X	
HUSSON, J.C.	CHIEF OF SCIENTIFIC RESEARCH CNES D.P. 4 91-BRETIGNY FRANCE	NO		5					X					

Table I-1 (continued)		INVITED TO 1970 ASF SCI.- OBJ. CONFERENCE (DID NOT ATTEND*)	COMMENTED ON PRELIMINARY CONFERENCE TRANSCRIPT	RECEIVED JANUARY 1972 MAILING (4 or 5 DOCUMENTS)	DECLINED TO PARTICIPATE	RESPONDED TO QUESTIONNAIRE	SUGGESTED ADDITIONAL SCIENTIST CONTACTS	RESPONDED FOR OTHER PERSONS	RECEIVED PRELIMINARY BASELINE SUMMARY	COMMENTED ON PRELIMINARY BASELINE SUMMARY	RECEIVED FINAL BASELINE SUMMARY	COMMENTED ON FINAL BASELINE SUMMARY	RECEIVED PROGRESS SUMMARY AND CONFERENCE INVITATION	ATTENDED 1972 ASF PRELIMINARY DESIGN CONFERENCE
INN, EDWARD (415) 961-3135	AMES RESEARCH CENTER CODE SSA MOFFETT FIELD, CALIFORNIA 94035	YES		4		X			X		X		X	
JEFFREYS, HAROLD	S&E AERO F.T. MARSHALL SPACE FLIGHT CENTER ALABAMA 35812	YES		4					X		X			X
JOHNSON, D.	DIRECTOR NATIONAL ENVIRONMENTAL SATELLITE SERVICE N.O.A.A. WASHINGTON, C.D. 20233	NO		5		X			X		X		X	
JOHNSON, F.S.	UNIVERSITY OF TEXAS AT DALLAS P.O. BOX 30365 DALLAS, TEXAS 75230	YES*		4		X			X		X		X	
JONES, A.V.	NATIONAL RESEARCH COUNCIL OF CANADA 100 SUSSEX DRIVE OTTAWA K1A OS1 CANADA	NO		5					X				X	
JONES, R.	DEPUTY DIRECTOR METEOROLOGICAL OFFICE LONDON ROAD BRACKNELL, BERKS. RG12 2UR ENGLAND	NO		5					X					
JUDGE, DARRELL L. (213) ·746-6150	DEPARTMENT OF PHYSICS UNIVERSITY OF SOUTHERN CALIFORNIA LOS ANGELES, CALIFORNIA 90007	YES	X	4					X		X		X	
KATZ, I. (301) 792-7800	APPLIED PHYSICS LAB JOHNS HOPKINS UNIVERSITY BALTIMORE, MARYLAND 21218	YES		5	X				NO					
KAWASAKI, T.	NATIONAL AEROSPACE LABORATORIES 1880 JINDAIJI MACHI, CHOSU TOKYO, JAPAN	NO		5					X					
KEATING, G.M. (703) 827-2576	LANGLEY RESEARCH CENTER CODE 62,640 HAMPTON, VIRGINIA 23365	YES	X	4					X		X		X	
KELLOG, W.W.	NCAR P.O. BOX 1470 BOULDER, COLORADO 80302	NO		5					X		X		X	
KESSLER, E., DIR.	NATIONAL SEVERE STORMS LABORATORY ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION 1616 HALLEY AVENUE NORMAN, OKLAHOMA 73069	NO		5		X			X		X		X	
KONRADI, ANDREI	NASA/MSC HOUSTON, TEXAS 77058													X
KRUEGER, ARLIN J.	GODDARD SPACE FLIGHT CENTER CODE 622 GREENBELT, MARYLAND 20771	YES		4					X		X		X	
KUHN, PETER N.	NOAA/ATMOSPHERIC PHYSICS & CHEMISTRY LAB R31 BOULDER, COLORADO 80302	YES		4		X			X		X		X	

Table I-1 (continued)		INVITED TO 1970 ASF SCI.-OBJ. CONFERENCE (DID NOT ATTEND*)	COMMENTED ON PRELIMINARY CONFERENCE TRANSCRIPT	RECEIVED JANUARY 1972 MAILING (4 or 5 DOCUMENTS)	DECLINED TO PARTICIPATE	RESPONDED TO QUESTIONNAIRE	SUGGESTED ADDITIONAL SCIENTIST CONTACTS	RESPONDED FOR OTHER PERSONS	RECEIVED PRELIMINARY BASELINE SUMMARY	COMMENTED ON PRELIMINARY BASELINE SUMMARY	RECEIVED FINAL BASELINE SUMMARY	COMMENTED ON FINAL BASELINE SUMMARY	RECEIVED PROGRESS SUMMARY AND CONFERENCE INVITATION	ATTENDED 1972 ASF PRELIMINARY DESIGN CONFERENCE
LANE, ARTHER	JET PROPULSION LABORATORY 230/136-B 4800 OAK GROVEDRIVE PASADENA, CALIFORNIA 91103	NO		5					X		X		X	
LEE, J.	NOAA 1313 HALLEY CIRCLE NORMAN, OKLAHOMA 73069													X
LONDON, JULIUS (303) 433-8759	DEPT. OF ASTROGEOPHYSICS COLORADO UNIVERSITY BOULDER, COLORADO 80302	NO		5					X		X			
MALCHOW, HARVEY	MIT CRAPER LABORATORY, MS#23 75 CAMBRIDGE PARKWAY CAMBRIDGE, MASSACHUSETTS 02142													2X
MARMO, F.F. (617) 275-9000	G.C.A. CORPORATION BEDFORD, MASSACHUSETTS 07130	YES*		4					X		X			
McCORMICK, B.M.	LOCKHEED MISSILES & SPACE CO. RESEARCH LABORATORIES 3251 HANOVER STREET PALO ALTO, CALIFORNIA 94303	NO		5					X		X			
McCOY, JOHN G.	HARVARD UNIVERSITY CAMBRIDGE, MASSACHUSETTS													X
MEGILL, L.R. (801) 752-7906	UTAH STATE UNIVERSITY LOGAN, UTAH 84321	YES		4		X			X		X		X	
MENDELL, W.	MAIL CODE TN4 MANNED SPACECRAFT CENTER HOUSTON, TEXAS 77058	YES		4					X		X		X	X
MULLER, H.G. DIRECTOR	INSTITUT FUR PHYSIK DER ATMOSPHARE DER DFVLR 8031 OBERPFAFFENHOFEN POST WESSLING FEDERAL REPUBLIC OF GERMANY	NO		5					X					
MUMMA, MIKE J.	GODDARD SPACE FLIGHT CENTER CODE 691 GREENBELT, MARYLAND 20771	YES		4					X		X		X	
MURCRAY, D.G. (303) 753-2627	DEPARTMENT OF PHYSICS UNIVERSITY OF DENVER DENVER, COLORADO 80210	YES		4					X		X		X	
MURPHY, RANDALL E. (617) 861-4903	A.F. CAMBRIDGE RESEARCH LABORATORY L.G. HANSCOM FIELD BEDFORD, MASSACHUSETTS 01730	YES		4					X		X			
NAGY, A.F.	UNIVERSITY OF MICHIGAN SPACE PHYSICS RESEARCH LABORATORY DEPT. OF ELECTRICAL ENGINEERING SPACE RESEARCH BUILDING 2455 HAYWARD ANN ARBOR, MICHIGAN 48105	NO		5		X	RICHARD STOLARSKI		X		X		X	X
NEY, E.P. (612) 373-4687	SCHOOL OF PHYSICS UNIVERSITY OF MINNESOTA MINNEAPOLIS, MINNESOTA 55455	NO		5					X		X			
NICOLET, M.M.	30 AVE DEN DOOM BRUSSELS 1180 BELGIUM	NO		5					X					

Table I-1 (continued)		INVITED TO 1970 ASF SCI.-OBJ. CONFERENCE (DID NOT ATTEND*)	COMMENTED ON PRELIMINARY CONFERENCE TRANSCRIPT	RECEIVED JANUARY 1972 MAILING (4 or 5 DOCUMENTS)	DECLINED TO PARTICIPATE	RESPONDED TO QUESTIONNAIRE	SUGGESTED ADDITIONAL SCIENTIST CONTACTS	RESPONDED FOR OTHER PERSONS	RECEIVED PRELIMINARY BASELINE SUMMARY	COMMENTED ON PRELIMINARY BASELINE SUMMARY	RECEIVED FINAL BASELINE SUMMARY	COMMENTED ON FINAL BASELINE SUMMARY	RECEIVED PROGRESS SUMMARY AND CONFERENCE INVITATION	ATTENDED 1972 ASF PRELIMINARY DESIGN CONFERENCE
NORTON, RICHARD B.	AERONOMY LABORATORY CODE R44 ENVIRONMENTAL RESEARCH LABORATORIES BOULDER, COLORADO 80302	NO		5					X		X		X	
NOXON, JOHN F. (617) 495-2829	BLUE HILL UNIVERSITY HARVARD UNIVERSITY CAMBRIDGE, MASSACHUSETTS 02138	NO		5					X		X			
OWEN, TOBIAS C.	SUNY, STONY BROOK DEPT. OF EARTH & SPACE SCIENCES STONY BROOK, L.I., NEW YORK 11790	NO		5		X			X		X		X	
PARESCE, F.	AY01 SPACE SCIENCES LABORATORY UNIVERSITY OF CALIFORNIA BERKELEY, CALIFORNIA 91103	YES	X	4		X		BOWYER	X		X		X	
PATTERSON,N. PAUL (703) 931-1598	UNMANNED PROGRAMS BELLCOM, INC. 955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024	NO		5					X					
PEARCE, GEOFFREY	BALL BROTHERS RESEARCH CORP. AEROSPACE DIVISION BOULDER INDUSTRIAL PARK BOULDER, COLORADO 80302	NO							X		X		X	X
PENROD, P.R.	NASA/MSC HOUSTON, TEXAS 77058													X
PEPPIN, T. (307) 766-4206	UNIVERSITY OF WYOMING PHYSICS DEPARTMENT LARAMIE, WYOMING 82070	NO		5					X		X			
PLASS, GILBERT (713) 845-3045	DEPT. OF PHYSICS TEXAS A&M UNIVERSITY COLLEGE STATION, TEXAS 77843	NO		5					X		X		X	
POTTER, A.E.	MAIL CODE TF MANNED SPACECRAFT CENTER HUSTON, TEXAS 77058	YES		4					X		X		X	X
PRAG, ARTHUR	AEROSPACE CORPORATION P.O. BOX 95085 LOS ANGELES, CALIFORNIA 90045	YES		4		X			X		X		X	
PRASAD, S.S.	ARECIBO IONOSPERIC OBSERVATORY ARECIBO PUERTO RICO	NO		5					X					
PRIESTER, N.	DIRECTOR INSTITUT FUR ASTROPHYSIKUND UND EXTRATERR FORSCHUNG 5300 BONN POPPELSDORFER ALLEE 49 FEDERAL REPUBLIC OF GERMANY	NO		5					X					
PRIOR, E.J.	M.S. 401-A BLDG. 1250 NASA LANGLEY HAMPTON, VIRGINIA 23365													X
RAMASUAMY, K.	ANNAMALAI UNIVERSITY DEPT. OF PHYSICS ANNAMALAINAGA INDIA	NO		5					X					

Table I-1 (continued)		INVITED TO 1970 ASF SCI.-OBJ. CONFERENCE (DID NOT ATTEND*)	COMMENTED ON PRELIMINARY CONFERENCE TRANSCRIPT	RECEIVED JANUARY 1972 MAILING (4 or 5 DOCUMENTS)	DECLINED TO PARTICIPATE	RESPONDED TO QUESTIONNAIRE	SUGGESTED ADDITIONAL SCIENTIST CONTACTS	RESPONDED FOR OTHER PERSONS	RECEIVED PRELIMINARY BASELINE SUMMARY	COMMENTED ON PRELIMINARY BASELINE SUMMARY	RECEIVED FINAL BASELINE SUMMARY	COMMENTED ON FINAL BASELINE SUMMARY	RECEIVED PROGRESS SUMMARY AND CONFERENCE INVITATION	ATTENDED 1972 ASF PRELIMINARY DESIGN CONFERENCE
RANDALL, CHARLES	AEROSPACE CORPORATION P.O. BOX 95085 LOS ANGELES, CALIFORNIA 90045	YES		4		X			X		X\		X	
RAWCLIFFE, R.D. (213) 648-7014	BLDG. 120, MAIL 1909 AEROSPACE CORPORATION SPACE PHYSICS LABORATORY P.O. BOX 95085 LOS ANGELES, CALIFORNIA 90045	YES	X	4		X		RANDALL PRAG	X		X		X	
REES, M.H. (303) 443-2211 (x 7501)	COLORADO UNIVERSITY LABORATORY FOR ATMOSPHERIC AND SPACE PHYSICS BOULDER, COLORADO 80302	NO		5		X			X		X		X	
RENSE, WILLIAM	LASP UNIVERSITY OF COLORADO BOULDER, COLORADO 80302													
ROBINSON, JOHN	NOAA ENVIRONMENTAL RESEARCH LAB CODE RX3 BOULDER, COLORADO 80302	NO		5					X		X			
ROBERTS, W.T.	CODE PD-MP-S MARSHALL SPACE FLIGHT CENTER ALABAMA 35812	YES		4					X		X		X	X
ROTTMAN, GARY	LABORATORY FOR ATMOSPHERIC AND SPACE PHYSICS UNIVERSITY OF COLORADO BOULDER, COLORADO 80302													1X
RUGGE, H.R.	THE AEROSPACE CORPORATION P.O. BOX 92957 LOS ANGELES, CALIFORNIA 90009													X
SAFFREN, M.M.	MAIL CODE 183-301 JET PROPULSION LABORATORY PASADENA, CALIFORNIA 91103	YES		4					X		X		X	
SCHUSTER, BURTON G.	NCAR P.O. BOX 1470 BOULDER, COLORADO 80302					X								
SEKERA, ZDENEK	U.S.A.R.W. GROUP SPACE SCIENCE CENTER INST. OF GEOPHYS. & PLANETARY PHYS. U.C.L.A. LOS ANGELES, CALIFORNIA 90024	NO							X		X		X	
SHARMA, R.D.	WILLOW RUN LABORATORY UNIVERSITY OF MICHIGAN P.O. BOX 618 ANN ARBOR, MICHIGAN 48104	YES		4					X		X		X	X
SHAW, JOHN H.	LABORATORY OF IR AND MOLECULAR PHYSICS OHIO STATE UNIVERSITY COLUMBUS, OHIL 43210	NO		5					X		X			
SHIMAZAKI, F. (303) 447-1000	INSTITUTE FOR TELECOMMUNICATIONS OF SCIENCE AND AERONOMY ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION, BOULDER, COLORADO 80302	NO		5					X		X			

Table I-1 (continued)		INVITED TO 1970 ASF SCI.-OBJ. CONFERENCE (DID NOT ATTEND*)	COMMENTED ON PRELIMINARY CONFERENCE TRANSCRIPT	RECEIVED JANUARY 1972 MAILING (4 or 5 DOCUMENTS)	DECLINED TO PARTICIPATE	RESPONDED TO QUESTIONNAIRE	SUGGESTED ADDITIONAL SCIENTIST CONTACTS	RESPONDED FOR OTHER PERSONS	RECEIVED PRELIMINARY BASELINE SUMMARY	COMMENTED ON PRELIMINARY BASELINE SUMMARY	RECEIVED FINAL BASELINE SUMMARY	COMMENTED ON FINAL BASELINE SUMMARY	RECEIVED PROGRESS SUMMARY AND CONFERENCE INVITATION	ATTENDED 1972 ASF PRELIMINARY DESIGN CONFERENCE
SILVERMAN, S.M. (617) 861-4832, 4735	AFCRL, OFFICE OF AEROSPACE RESEARCH L.G. HANSCOM FIELD BEDFORD, MASSACHUSETTS 01730	NO		5	X				NO					
SIMPSON, R.H.	DIRECTOR NATIONAL HURRICANE CENTER P.O. BOX 8286 UNIVERSITY OF MIAMI CORAL GABLES, FLORIDA 33124	NO		5	X	X			NO					
SMITH, ROBERT E.	CODE S&E AERO YS MARSHALL SPACE FLIGHT CENTER ALABAMA 35812	NO		5					X		X			
SMITH, S.D.	J.J. THOMPSON PHYSICAL LAB UNIVERSITY READING ENGLAND	NO		5					X					
SPENCER, N.W.	GODDARD SPACE FLIGHT CENTER CODE 620 GREENBELT, MARYLAND 20771	NO		5					X		X			
STAIR, A.T. (617) 861-4910, 4911	A.F. CAMBRIDGE RESEARCH LABORATORIES L.G. HANSCOM FIELD BEDFORD, MASSACHUSETTS 01730	YES		4					X		X		X	
STEBBINGS, R.F.	SPACE SCIENCES DEPARTMENT RICE UNIVERSITY 6100 SOUTH MAIN STREET HOUSTON, TEXAS 77001	NO		5		X			X		X		X	
STOLARSKI, RICHARD	NASA/MSC CODE TN HOUSTON, TEXAS 77058													X
STEED, A. (801) 752-4100	UTAH STATE UNIVERSITY LOGAN, UTAH 84321	YES		4					X		X			X
SUOMI, V.E. (608) 262-2172	SPACE SCIENCE & ENGINEERING CENTER UNIVERSITY OF WISCONSIN 1225 WEST DAYTON STREET MADISON, WISCONSIN 53706	NO		5					X		X		X	
TAKAYANGI, K.	INSTITUTE FOR SPACE AND AERONAUTICAL SCIENCE UNIVERSITY OF TOKYO TOKYO, JAPAN	NO		5					X					
TEPPER, M.	CODE ERD NASA HEADQUARTERS WASHINGTON, D.C. 20546	NO		5					X		X		X	
THEKAEKARA, M.P.	CODE 322 GODDARD SPACE FLIGHT CENTER GREENBELT, MARYLAND 20771	NO		5		X			X		X		X	X
THOMAS, L.	SCIENCE RESEARCH COUNCIL RADIO AND SPACE RESEARCH STATION SLOUGH, BUCKS, ENGLAND	NO		5					X					
TINSLEY, B.A. (214) 231-1471	UNIVERSITY OF TEXAS AT DALLAS P.O. BOX 30365 DALLAS, TEXAS 75230	NO				X		JOHNSON HANSON	X		X		X	X

Table I-1 (concluded)		INVITED TO 1970 ASF. SCI.-OBJ. CONFERENCE (DID NOT ATTEND*)	COMMENTED ON PRELIMINARY CONFERENCE TRANSCRIPT	RECEIVED JANUARY 1972 MAILING (4 or 5 DOCUMENTS)	DECLINED TO PARTICIPATE	RESPONDED TO QUESTIONNAIRE	SUGGESTED ADDITIONAL SCIENTIST CONTACTS	RESPONDED FOR OTHER PERSONS	RECEIVED PRELIMINARY BASELINE SUMMARY	COMMENTED ON PRELIMINARY BASELINE SUMMARY	RECEIVED FINAL BASELINE SUMMARY	COMMENTED ON FINAL BASELINE SUMMARY	RECEIVED PROGRESS SUMMARY AND CONFERENCE INVITATION	ATTENDED 1972 ASF PRELIMINARY DESIGN CONFERENCE
TORR, D.G.	SOUTH AFRICAN COUNCIL FOR SCIENTIFIC & INDUSTRIAL RESEARCH NATIONAL INSTITUTE FOR TELECOMMUNICATIONS RESEARCH JOHANNESBURG REPUBLIC OF SOUTH AFTICA	NO		5					X					
TOTH, ROBERT (213) 354-5164	183B/353 JET PROPULSION LABORATORY LUNAR AND PLANETARY SCIENCES SECTION PASADENA, CALIFORNIA 91103	YES		4		X			X		X			
VAUGHAN, W.W. (205) 453-3106	CHIEF, AEROSPACE ENVIRONMENT DIVISION AERO-ASTRODYNAMICS LABORATORY NASA/MARSHALL SPACE FLIGHT CENTER ALABAMA 35812	NO		5					X		X			
VOGL, JOE	TRW SYSTEMS 1 SPACE PARK REDONDO BEACH, CALIFORNIA												X	
VONDER HAAR, T.H. (303) 491-8555	DEPT. OF ATMOSPHERIC SCIENCE COLORADO STATE UNIVERSITY FORT COLLINS, COLORADO 80521	NO		5		X			X		X			
WAND, R.H. (617) 692-4761	LINCOLN LABORATORY MASSACHUSETTS INSTITUTE OF TECHNOLOGY CAMBRIDGE, MASSACHUSETTS 02139	NO		5	X				NO					
WARD, GRAY	DEPARTMENT OF PHYSICS UNIVERSITY OF FLORIDA GAINESVILLE, FLORIDA 32601	NO		5					X		X			
WILLMORE, A.P.	UNIVERSITY COLLEGE LONDON ENGLAND	NO	5						X					

B. SUMMARY

Task I, *Science Objectives Study,* was initiated in November 1971 with the activity of transcribing the voice tapes of the September 1970 meeting at NASA-MSC for publication, and terminated on schedule at the end of April 1972. The following report describes the approach taken for the study and the contacts with the scientific community. National goals and programs in atmospheric research are reviewed, after which a presentation of the results of the study is given. Eight major research objectives for the facility were identified, addressing not only areas of basic knowledge of the atmosphere, but also areas of contemporary practical interest. The range of experiments suggested by the scientific community were examined, and the critical design parameters for the facility instrumentation established, taking due account of the particular constraints imposed on observations to be performed on Shuttle and in Earth orbit.

Task II, *Spectrometer Preliminary Design Study,* began on March 1, 1972, with a review of current technology in instrument systems and components, and terminated on schedule at the end of October 1972. The report presents the results of the review and the preliminary performance requirements for ASF instrumentation. Virtually all of the objectives for the facility can be achieved using either state-of-the-art design concepts or concepts that have a high likelihood of becoming a reality by the time the ASF would be operational. Observationally, at least three instrument clusters will be required to accomplish the objectives, performing atmospheric observations, solar monitoring, and previewing functions, respectively. It will be necessary to supplement general-purpose instruments with a capability for carrying a variety of special-purpose instruments, as well.

Task III, *Telescope/Pointing Controls Preliminary Design Study,* began on April 1, 1972, with a review of current technology in collecting optics and pointing systems, and terminated on schedule at the end of October 1972. The report presents the results of the review and the preliminary performance requirements for the ASF pointing system. For work on extended atmospheric sources, only small aperture, short focal ratio collecting optics will be necessary, allowing individually tailored collectors to be incorporated into each instrument design, and making possible pointable clusters of instruments.

Task IV, *Presentation of Findings,* was initiated by a meeting of atmospheric scientists at NASA-MSC in October 1972. The purpose of that meeting was to review the results of the study up to that time, and to provide additional input material for the definition of objectives and performance requirements for the ASF. The participants at that meeting felt that emphasis should be placed on maintaining the definition of objectives in a fluid state, allowing them to evolve as new areas of research develop. Comments were also made on the importance of maintaining the results of the study in the form of performance requirements, rather than in the form of specific instrument designs, no matter how preliminary. Task IV also had as a major activity the incorporation of the results of the meeting into the definition of objectives and preliminary performance requirements for the ASF. The results of that meeting are reflected throughout the report in the sections to which they apply. Several new areas of research were advanced, such as expanded solar observations, the use of active optical systems, *in-situ* measurements, polarimetric observations, and others. All have received consideration, and the report presents these results, as well.

Task V, *Instrument Preliminary Development,* was a new task that was added to the contract in August 1972. It started in November 1972 and runs through January 1973. This task is concerned with the preparation of specifications for, and identification of potential suppliers of, the instruments most likely to be contained in the ASF. This task also required the preparation of requests for proposal for laboratory breadboards and airplane prototype hardware. In recent months, it has become increasingly clear that the near-term emphasis for ASF has shifted away from this area, as discussed above under Task IV, and more fully in Section VI-D of this report.

II. SCIENTIFIC OBJECTIVES AND REQUIREMENTS

A. INITIAL STUDY CONCEPTS

The fundamental purpose for the study was to establish the scientific objectives, range of experiment types, and experimental design requirements for a reusable, manned, general-purpose optical facility that would perform atmospheric research from Earth orbit. A proposed Space Shuttle payload for the late 1970s, the Atmospheric Science Facility (ASF) would be carried into orbit for sortie missions of from seven to 30 days and then would be returned to Earth with the Shuttle Orbiter. The spaceborne atmospheric research platform would be available to the international community of scientists and would provide them with a sophisticated complement of general- and special-purpose instruments to perform their research. For an anticipated 10-year lifetime or more, changes expected in the research objectives would be accommodated by a flexible and evolving mix of instrumentation. Finally, the ASF would undertake research that would be complementary to other major atmospheric programs, taking advantage of the unique attributes of the Shuttle delivery system, such as large payload weight and volume, and ample electric power.

B. STUDY APPROACH (CONTACTS WITH AND INVOLVEMENT OF THE SCIENTIFIC COMMUNITY)

To accomplish the fundamental purpose of the preliminary design study, the approach taken was to contact the community of atmospheric scientists, to present the above opportunity to them, and to request that the objectives for the ASF be established by them, through their responses. An important factor in this approach was that the objectives for the facility were to be established before the design of instrumentation in the hope that a maximum of scientific benefit would result with a minimum of instrumental restrictions on the objectives.

In September 1970, a conference was held at NASA's Manned Spacecraft Center and attended by approximately 40 atmospheric scientists from all parts of the United States to discuss the objectives for such a facility. After a period for review and comment on the preliminary conference proceedings by the conference participants, a questionnaire was distributed in January 1972 to an expanded list of scientists, eventually numbering about 130, in which the scientist was requested to express his opinions regarding the objectives for the ASF and to give a detailed description of experiments required to accomplish those objectives.

In the following several months, approximately 100 persons were contacted as the study proceeded, maintaining a continuing input while keeping the scientific community aware of the developments in the program. The results of the study were presented at a review conference of atmospheric scientists in October 1972, at NASA-MSC, and, from that conference, the science objectives and instrument preliminary designs were updated to reflect those inputs through additional correspondence with the conference participants and other specialists.

C. NATIONAL GOALS AND PROGRAMS IN THE ATMOSPHERIC SCIENCES

Committees in the fields of atmospheric science, remote sensing, pollution, and the Space Science Board under the National Research Council have established national goals in the disciplines that relate to the work of the ASF. These include the long-range goals in meteorology and the atmospheric sciences, emphasizing the ability to make useful prediction of the weather, by numerical simulation on large computers, for periods of up to two weeks. Associated with this is research into the dynamics of climate and the ability to forecast mesoscale phenomena (those occurring over a 2- to 12-hr period). A second goal has been the study of atmospheric pollutants, which have become a topic of current interest among scientists and the public at large.* Specific recommendations for the study from spacecraft of atmospheric contaminants have been made by two recent conferences of specialists in environmental science and remote sensing.†§ The alteration of the Earth's surface through deforestation, the creation of urban

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**The Atmospheric Sciences and Man's Needs - Priorities for the Future*. Committee on Atmospheric Sciences, National Research Council, National Academy of Sciences, Washington, DC, 1971.

†*Man's Impact on the Global Environment*. Report on the Study of Critical Environmental Problems, Massachusetts Institute of Technology, 1970.

§*Remote Measurement of Pollution*. NASA SP-285. National Aeronautics and Space Administration, Washington, DC, 1971.

heat islands, injection of warm discharges into lakes and streams, and injection of particulate matter into the atmosphere along with gases such as CO_2 raise the possibility of inadvertent alteration of the Earth's climate. Experiments to measure the Earth's radiation budget by very accurate monitoring of the incident solar energy and the reflected and emitted outgoing flux are being developed for the latter half of the 1970s. The determination of the channels through which the solar energy is radiated from the Earth, and the possible effects that human activities might have in altering these processes, is a topic that is certain to become more important as human population increases and becomes more industrialized.

A third goal has been the study of the complicated physical and chemical processes that occur in the mesosphere and thermosphere.*

A chronological layout of satellite programs in the atmospheric sciences for the 1970s is given in Fig. II-1. Because most of the weather observations will be made from unmanned satellites, the only ASF activity in this area is expected to be special-purpose research flights. Many of the air pollution experiments developed in the Advanced Applications Flight Experiments (AAFE) program could fly on the ASF. The ability of the astronaut to direct the instrumentation to special meteorological features and the return of the sensors to the ground to ensure calibration accuracy will make the ASF valuable for the Earth radiation budget measurements. With additional *in-situ* sensors and subsatellites, ASF could continue studies in aeronomy at the time when the Atmospheric Explorer program is coming to an end.

1. National Programs in Atmospheric Sciences

a. Meteorology - Current efforts in meteorological research are directed toward the goal of improving forecast ability from the present two- to three-day period to a time span of two weeks. Computerized forecasts using numerical models of the atmosphere are the chief method used to achieve the long-range forecasts. To provide the greatly increased amount of input data required to make accurate long-range computer forecasts possible, satellite systems are being designed to provide global coverage of

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**Physics of the Earth in Space, A Program of Research: 1968-1975.* Report of a Study by the Space Science Board August 1968, National Academy of Sciences, National Research Council, October 1968.

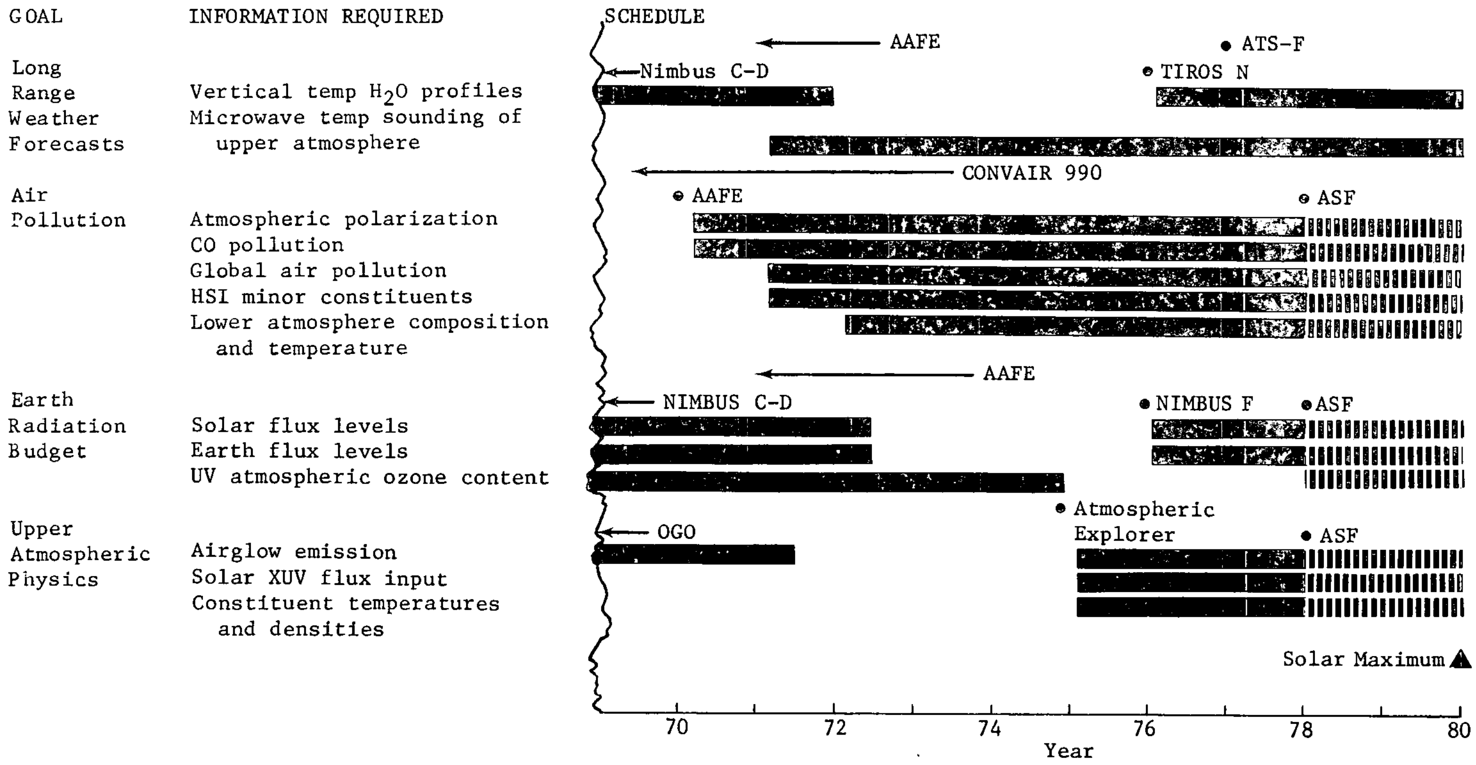

Fig. II-1 Major Research Goals and Programs in the Atmospheric Sciences the visible and infrared radiation emitted or reflected from the Earth; measure vertical temperature, ozone, and humidity profiles; and to provide a data collection relay system for remotely located instrumentation.

Global Atmosphereic Research Program (GARP) - An international co-operative research effort to provide an increasing understanding of the general circulation of the atmosphere and to provide a mathematical analysis and physical measurement basis for long-range measurement has been in a planning stage for the last decade. At present, several countries are starting to implement the programs required to support the GARP.* The observational network required to implement long-range predictions is called the World Weather Watch. There are 132 national weather services joined in an effort to improve meteorological services and communicate data to processing centers for rapid world-wide dissemination.

Three requirements have been identified as essential to GARP's objective of attaining economically useful long-range weather prediction:

1) Development of a global observing capability;

2) Increase of computer speeds by a factor of 100 to enable the data processing capability to be able to cope with a set of global observations;

3) Conducting of regional field observation programs and computer modeling experiments to improve the physical and mathematical basis of long-range predictions.

Several problems must be overcome before long-range global forecasts become a reality. The first step is to greatly expand the observational data base. Except for North America and Europe, meteorological observation stations are not spaced closely enough to provide the density of coverage needed. Over large areas of the oceans, data are almost totally lacking, particularly in the Southern Hemisphere. Merchant ships and aircraft traversing the region are not properly equipped with instrumentation and trained observers to report more than the obvious features, such as storms, and the information does not get reported in a timely fashion so that it can be used for operational forecasting.

**Plan for U.S. Participation in the Global Atmospheric Research Program.* U.S. Committee for the Global Atmospheric Research Program, National Research Council, National Academy of Sciences, Washington, DC, 1969.

An estimate of observational requirements has been made by the World Meteorological Organization. On a 400-km horizontal resolution scale, measurements of the following quantities are to be made at eight levels between ground level and 10 millibars (about 100,000 ft) once or twice daily: wind velocity, temperature, pressure, relative humidity, and sea surface temperature. Other quantities of interest are ozone, soil moisture, and ice and snow cover.

The meteorological satellite program has greatly increased the global coverage of meteorological data. The addition of vertical sounders for temperature and humidity to future operational satellites will represent a significant advancement in providing forecast information for the 80% of the Earth's surface for which data are presently lacking. By the end of the decade, the use of hundreds of balloons and buoys interrogated by satellite will even further expand meteorological data gathering capability.

A second class of problems relates to the physical models and mathematical computational techniques used to calculate the future dynamic state of the atmosphere. Fluid dynamics theory gives the basic physical equations, but their complexity, and the difficulty in estimating terms such as frictional dissipation, forces the practical expedient of neglecting such terms as radiation input and transfer. Nevertheless, to cover one hemisphere of the globe with a three-dimensional grid of points, about which the computations are performed by numerical iteration techniques, taxes the capability of the largest and fastest computer systems in existence. Current numerical simulation research is directed toward determining optimum grid sizes, time integration periods, and approximations that will simplify the computations, yet retain the accuracy required to produce a useful forecast.

Another limitation on numerical modeling accuracy arises from the inherently turbulent nature of the fluid flow. While large-scale aspects of the flow are adequately monitored by the synoptic observational network, the smaller scale flows responsible for the transfer of energy, momentum, heat and water vapor are too detailed to describe. Yet, ultimately, the major scale flow must be determined by the effectiveness of the interactions with the smaller scale phenomena.

During the 70s, the international meteorological community plans to build the global observational network and perform the tropical ocean atmosphere interaction experiments that will make long-range numerical forecasting an established meteorological operating tool. Operational meteorological satellites with expanded capabilities will make observations from outside the atmosphere and relay data from balloons, unmanned observing stations in remote areas, and buoys. The development of an appropriate buoy network that is economically feasible is the main pacing item in the field of instrumentation.

A series of tropical meteorology experiments involving large numbers of investigators in coordinated observations from satellites, aircraft, ships, and island stations is in progress to define the measurement network and physical interactions significant in tropical meteorology. The Line Islands Experiment and the Barbados Oceanographic and Meteorological Experiment (BOMEX) have already provided data and experience in conducting large-scale programs of this type. The GARP Atlantic Tropical Experiment will be conducted in the summer of 1974 to provide observations on a large oceanic area.

A full-scale test of our ability to observe and predict on a global scale is planned for 1976 in the First GARP Global Experiment (FGGE). It is anticipated that follow-on experiments to investigate tropical meteorology will occur during the operational time of Shuttle and ASF.

Meteorological Satellite Programs - The United States meteorological satellite program, principally the TIROS and NIMBUS series, has addressed the needs of both the research worker and the operational meteorological forecaster. Experiments put up in a research status have quickly become integrated into the operational system once feasibility was demonstrated.

The TIROS Series - As designated by its acronym, TIROS (Television and Infrared Observation Satellite) has carried only video sensors and IR scanners in the atmospheric window region of the spectrum. While the video sensors provided high resolution imagery on the daylight side of the orbit, the infrared scanners mapped cloud cover at night, because the cloud tops were colder than the temperature of the surface underneath. During the 1960s, the IR scanner resolution increased and onboard calibration was provided so that quantitative data could be received on cloud top temperatures, sea surface temperatures, and the amount of ice and snow cover in the Arctic regions. At present, all TIROS launches are for operational data used in forecasting.

The NIMBUS Series - Instrument development has been carried out on the larger, three-axis-stabilized NIMBUS spacecraft. Advanced video cameras and infrared scanners, later to be incorporated into the TIROS observational system, were tested on the first NIMBUS. Additional radiometer channels allowed water vapor, CO_2 radiation, and reflected solar energy to be measured. A significant improvement in the capability to measure the vertical distribution of temperature, water vapor, and ozone was achieved by including the Satellite Infrared Spectrometer (SIRS) and Infrared Interferometer Spectrometer (IRIS) experiments. Later experiments used different optical techniques but achieved the same objective. Monitoring of the solar flux in the ultraviolet has been done with a five-channel photometer and with a small spectrometer that also measures the vertical ozone distribution. Future NIMBUS experiments will extend sounding techniques into the microwave region of the spectrum where less blockage of the measurements by clouds will be experienced. Another significant forthcoming experiment will measure the Earth radiation budget by accurately monitoring the incident solar, the reflected solar, and the emitted long wave radiation from the Earth.

Applications Technology Satellite (ATS) - A spin scan camera on the ATS in synchronous orbit has enabled cloud motion photographs to be taken of an entire hemisphere, from which average wind velocities can be derived. Future ATS experiments will include a temperature and humidity sounder to provide additional coverage in tropical areas, and hemispherical monitoring of the radiation budget.

Operational System for the Late 1970s - The operational meteorological sensor system for the late 70s is being designed. Requirements call for a high resolution scanning radiometer covering the visible and IR regions, vertical sounders for temperature, water vapor, and ozone, and an interrogation system for balloons and ocean buoys. Two satellites will be operational at any one time, giving four observations per day (for a geographic location outside of the polar regions).

All meteorological satellites have been flown in polar orbits that are retrograde and inclined 78 deg to the equator. This orbit gives full global coverage but results in gores (sections between two meridian lines) around the equator that are not covered. A 1000-km altitude maximizes coverage and is consistent with radiation belt fluxes. The plane of the 78 deg retrograde orbit precesses at the rate of 1 deg/day so the equatorial crossing always takes place at the same phase angle with respect to the sun.

b. Air Pollution - Recent interest in the effects of human activity on the quality of the environment has led to the desire to monitor the concentrations and geographic dispersion of atmospheric trace gases and aerosols. Because of the global coverage that can be obtained from satellites, the development of suitable instrumentation for the quantitative determination of both natural and man-made trace gases is being vigorously pursued.

The necessity for assessing the long-term ecological effects of human activity was emphasized in a study of critical environmental problems sponsored by the Massachusetts Institute of Technology. In a report entitled *Man's Impact on the Global Environment*, the following recommendations were made with regard to initiating national programs: (1) new methods of data gathering and the establishment of ecological measurement standards should be implemented to form the basis for a global ecological quality monitoring system, (2) the CO_2 content of the atmosphere should be monitored for long-term increases due to the burning of fossil fuels, (3) the optical properties of aerosols emitted into both the troposphere and stratosphere should be determined so that heating or cooling effects due to an increase in albedo can be evaluated, (4) solar radiation measurements should be improved and the Earth's albedo should be monitored to an accuracy of better than 1%, (5) the vertical distribution of particulates should be measured by lidar systems and specific particles and gases should be monitored by chemical techniques, and (6) the effects of atmospheric particulates on atmospheric radiation should be included in computer simulations of the global circulation of the atmosphere.

Global observations of the temporal variations of cloud distributions and a determination of their infrared properties are required to evaluate their role in the Earth's heat budget. The effects of engine exhaust products of supersonic transports on the stratosphere should be determined. Clouds resulting from water vapor, oxides of nitrogen and sulfur, hydrocarbons and particulate matter are all substances that could cause climatological effects from a large fleet of planes.

The detection of atmospheric contaminants by remote sensing techniques was the subject of a report by a NASA working group. The panel on gaseous air pollution concluded that O_3, H_2O, NO, NO_2, HNO_3, and CH_4 play an important role in determing ozone photochemistry and radiative equilibrium and should be monitored. This panel concluded that adequate techniques exist for the monitoring of CO, SO_2, NO_2, NO, and CO_2.

c. Radiation Measurements - Particulate matter in the atmosphere has effects ranging from the local pollution of cities to altering the radiation balance of the Earth on a global basis. Localized measurements show that in some cities the long-term average of solar radiation reaching the ground is reduced by particles by more than 10%. The global effect is more difficult to assess, because adequate data have not been collected over a sufficiently long period. The optical constants of the aerosol particles must be determined so that an assessment of the increase in albedo against the absorption of long-wave radiation can be made.

It will be necessary to establish a world-wide monitoring system that will enable the long-term trends in atmospheric particulate concentrations and compositions to be established as well as the effects on the received and emitted terrestrial radiation to an accuracy of better than 1%. Ground stations and satellite systems for the determination of atmospheric turbidity and aerosol content should be established. Mathematical models for determining the scattering properties of aerosols must be improved.

d. Advanced Applications Flight Experiments (AAFE) - Because of the long lead time necessary to develop some complicated experiments, NASA has established the AAFE program to begin experiment development before a definite flight opportunity is determined. Often a period of several years of data gathering from aircraft and balloons and refinement of the experiment instrumentation parameters will elapse between inception of the experiment and fabrication of the flight instrument. The air pollution sensing instruments will have their data checked against ground-based measurements. Meteorological sensors will have their outputs checked against radiosonde data.

e. Upper Atmospheric Physics

Orbiting Geophysical Observatory Program - The Orbiting Geophysical Observatory series consisted of six satellites launched from 1964 to 1969 to explore the complicated interaction between solar phenomena and the Earth's magnetosphere. About 24 experiments were carried on each satellite in the following areas: low-energy solar cosmic rays and galactic cosmic rays, electron density and temperature, solar X-ray and ultraviolet radiation, solar plasma, intensities and gradients of electric and magnetic fields, VLF emissions, micrometeoroid emissions, spatial distributions and variations in the aurorae and airglow, celestial Lyman alpha, sodium airglow, auroral particles, solar flares, electromagnetic energy sources contributing to ionization and atmospheric heating, and the densities and masses of both neutral and ionized atmospheric species.

Atmospheric Explorer Program - Because of the complexity of aeronomical processes, a well-coordinated approach to data gathering by a team of both experimentalists and theoriticians was proposed by the investigators on the Atmospheric Explorer. The scientific objective of the mission is to investigate the chemical and energy conversion processes that control the structure of the thermosphere through simultaneous measurements of its structural properties and the airglow parameters that provide information on the rates of controlling aeronomic processes. By incorporating a propulsion system into the satellite, it will be possible to explore the low altitude region between 120 and 300 km and restore orbital velocity lost to atmospheric drag.

In the lower thermosphere, between 100 and 250 km, ultraviolet radiation from the sun is absorbed, producing the ions and electrons of the ionsphere. Diffusion occurs to higher altitudes, governing the densities that occur. Electron and ion temperatures at the higher altitudes are influenced by thermal conduction from below. At the low altitudes the transport phenomena are less important, and densities and temperatures are determined by local processes of chemical equilibrium for electron and ion densities, and equilibrium between heating and cooling rates governs the temperatures. To resolve discrepancies between experimental data and theory, simultaneous measurements are needed of ultraviolet fluxes, neutral densities, temperatures, and ion and electron densities.

Atmospheric densities in the thermosphere and exosphere have mainly been determined from satellite drag measurements. Variations shorter than the satellite period, or variations localized geographically could not be seen. The Atmospheric Explorer will measure densities directly with a mass spectrometer and provide higher resolution definition of localized disturbances. Horizontal gradients of density and temperature will also be explored.

Specific problems to be studied by the Atmospheric Explorer include mapping the ion and neutral composition and determination of reaction rates, determing the heating of photoelectrons and their cooling rates for reactions with ions and neutrals, the thermal balance of ions, the spatial distributions of electron and ion temperatures, determination of rate coefficients that affect the heat budget, determination of the enhanced heating during magnetospheric disturbances, prediction of low energy electron spectra during geomagnetically quiet and disturbed conditions and aurorae, the 6300 Å airglow photodissociation, photoelectron impact excitation of oxygen, the role of conjugate photoelectrons in predawn airglow enhancement, the altitude and spatial distribution of auroral forms, and the global structure and dynamics of the neutral atmosphere.

D. OBJECTIVES, RESEARCH AREAS, AND MEASUREMENT TECHNIQUES

1. Science Objectives

From early conference material, responses to questionnaires, and, most recently, from the results of the October 1972 Science Review Conference, a set of eight scientific objectives for an Atmospheric Science Facility has been derived. These objectives reflect the broad application of the ASF, addressing areas of new knowledge about the atmosphere, as well as timely topics of practical interest:

1) Atmospheric composition - The major and minor constituents of the atmosphere;

2) Atmospheric structure - The distribution of the constituents of the atmosphere, in both the vertical direction and over the Earth's surface;

3) Atmospheric processes - The chemical and photochemical reactions in the atmosphere, and reaction rates;

4) Atmospheric dynamics - The forces acting on the atmosphere--atmospheric motions;

5) Radiation budget - The total and geographically localized balance of radiation received versus scattered and emitted radiation--the energy source function for the atmospheric system;

6) Atmospheric pollution - Natural and artificial contaminants and their short- and long-term effects on atmospheric structure, weather, and climate;

7) Earth observations - Calibration of the transmission medium for remote sensing applications--detailed research on specific surface features;

8) Astronomy - Extraterrestrial observations not related to Earth atmospheric studies.

Under each of the objectives, several research areas have been identified, the study of which may contribute to the solution of the questions inherent in the name of the objective. In addition to areas of research, potential measurement techniques that may be employed in the pursuit of these questions will be presented.

It should be emphasized that the objectives, research areas, and measurement techniques presented here derive from inputs from the atmospheric science community; it is very difficult to predict the important objectives of scientific research several years ahead of time. In most cases, the research suggestions received were based on the individual scientist's assessment of current problems in his field. However, it is felt that this is the most reasonable starting point in any definition of a research facility such as ASF.

2. Discussion of Objectives and Underlying Research Areas

a. Atmospheric Composition - Atoms, ions, and molecules that are found in the atmosphere will be measured using both *in-situ* measurements with mass spectrometers and remote sensing of the optical emissions and absorptions. *In-situ* probes will measure the densities of molecules, ions, atoms, and the densities and energy distributions of charged particles as functions of altitude and geographical location. Airglow and auroral optical emissions will be used to identify the constituents and energy state of the emitting source by their characteristic optical wavelengths. Aerosols will be studied by their effect on the spectral distribution and polarization of scattered sunlight.

b. Atmospheric Structure - Detailed distributions of the atmospheric constituents will reveal structure in both horizontal and vertical dimensions. Vertical distributions may vary over distances of a few kilometers (for constituents such as water vapor) to several tenths of an Earth radius (for the outer components of the exosphere). Structure may change diurnally, seasonally, or with geographic position, either over global scales, or with small-scale dimensions such as the distribution of water vapor around a thunderstorm or weather front. Thermal structure will be determined from the analysis of CO_2 absorption line profiles and from horizon scans of emitting species or solar/stellar occultations. The distribution of aerosols, haze, thin cirrus, and other scattering components will affect optical depth determinations for solar radiation and local sources of pollution and dispersal mechanisms will produce horizontal distributions of trace constituents.

c. Atmospheric Processes - The deduction of the chemical and photochemical reactions involving the observed atmospheric constituents is one of the most complicated and difficult tasks facing the analyst of ASF data. Many of the steps in the reaction processes are not observable directly and must be deduced from known rate coefficients, measured concentrations, and reactions that produce optical emissions. The determination of ionospheric processes will require other types of data in addition to measurements of optical emissions and the concentrations of ions and neutral molecules. The energy spectra of photoelectrons and high-energy charged particles must be measured, particularly in auroral zones. The density and thermal energy of the free electrons in the plasma must be known, as well as the nature of the ionizing solar energy. Accurate measures of both the intensity and the line profiles are required to determine the absorption cross-section as a function of depth and zenith angle in the atmosphere. Simultaneous observations of solar radiation and the atmosphere will permit determination of the response to transient events such as solar flares. Analysis of airglow and auroral emissions can reveal the energy states to which the atoms and molecules are excited.

The generation and removal processes for pollutants and aerosols are important lower atmosphere processes. The thermal and energy budgets for meteorological phenomina will be explored.

d. *Atmospheric Dynamics* - Measurement of the physical motion of the upper atmosphere is due to ionospheric winds caused by electric fields and atmospheric tides and gravity waves. The velocity and temperature of the emitting species could be measured with high spectral resolution Fabry-Perot interferometry. Spatial and temporal variations in the temperatures and concentrations of species, their optical emissions and the fluxes and energy spectra of charged particles and electrons can reveal horizontal and vertical transport of constituents during transient phenomina such as geomagnetic disturburances and twilight conditions. Turbulence and diffusion cause the vertical transport of many species. The interaction of the atmosphere with the magnetosphere is an important area for ASF research into plasma interactions and solar disturbance effects as manifested in auroral phenomena.

The generation of aerosols from volcanic and industrial fumes and the processes of dispersal could be observed on a global basis from the ASF. Other trace constituents would permit the monitoring of winds at lower levels.

e. *Radiation Budget* - The ASF would perform both local and global assessments of the balance between the incident and reflected solar energy and the emitted infrared energy from the Earth. Assessment of this balance is essential not only to understand long term climatological effects such as ice ages, but also to determine if the effects of man-made pollution can lead to significant climatic changes. Very accurate measurements of this type are only now possible due to the progress of space technology.

The solar input radiation will have to be measured in both its total energy input and in its spectral distribution to determine these quantities accurately from outside the atmosphere, and to monitor any variations, which are suspected to be of only a few percent in magnitude.

On a global basis, the reflected and emitted radiation would be measured in sufficiently narrow bandwidths over the total surface of the Earth so that the net balance in the absorption and emission of radiation can be determined when combined with temperature and water vapor distributions. For localized measurements, the influence of meteorological features such as weather fronts, hurricanes, and squall lines on the radiation budget should be determined.

f. Atmospheric Pollution - The detection, measurement and mapping of the geographic distributions of natural and man-made trace substances in the atmosphere requires the most sensitive instrumentation due to the low signal levels. The monitoring of pollution levels becomes urgent because the increasing amounts of foreign gasses and dust put into the atmosphere by man's activities may be capable of affecting the Earth's heat balance and of disturbing-natural climatic cycles. The radiation balance can be changed by dust and aerosols that increase the albedo; by CO_2 that traps IR radiation; or by stratospheric water vapor, by increasing atmospheric turbidity and affecting the processes of radiation transfer. It would be important to monitor the stratosphere to determine the background levels of water vapor and other trace gasses before fleets of supersonic transports inject large quantities of water vapor, nitrogen oxides and other gasses into these levels of the atmosphere.

The mechanisms of pollution injection would be studied to determine loads from natural sources such as volcanos or man made industrial sources. Dispersal mechanisms such as diffusion and winds would be evaluated to study phenomena such as the tendency of aerosols to be found in layers. Time and space variations in concentrations would be measured and residence times in the upper and lower atmosphere would be observed. The chemical and photochemical reactions of pollutants would be examined and removal processes such as rainout and absorption into soil and water studied.

The measurement techniques to be used could include high-resolution IR absorption spectroscopy and Raman scattering for gasses, and Lidar backscatter and polarimetry for aerosols. Radiometric limb scan measurements and occultations could be used to measure pollutants at high altitudes. Man-made gasses to be monitored include the gasses NO, NO_2, N_2O, HNO_3, OH, O_3, CH_4, CO_2, CO, SO_2, H_2S, PAN, etc.

g. Earth Observations - Because the ASF instruments would be capable of making narrow field-of-view measurements over a broad spectral range, they could also be used to obtain the spectral signatures of surface objects, in addition to atmospheric features. The range of target subjects that might be observed is very broad and includes rock and soil types, vegetation cover and its seasonal changes, agricultural growth cycles and the detection of plant disease, observation of ocean surface features and the pollution of lakes and rivers, and the thermal mapping of both water and land features.

The transmission of the intervening atmosphere must also be evaluated for proper interpretation of any surface spectral data collected by ASF or other orbital systems. Aerosol content and water vapor distribution with height are significant parameters determining the atmospheric absorption. In general, the optical depth must be evaluated as a function of wavelength. Other meteorological parameters of significance in data reduction include cloud patterns, particularly the presence of thin cirrus, and precipitation occuring at the time of Earth resource observation or a short time previously.

h. Astronomy - It also would be possible to observe bright astronomical objects with instrumentation designed to observe atmospheric features. The ultraviolet, visible, and infrared spectrometers and interferometers would permit unobscured, higher spectral resolution observations to be made of astronomical objects, from 0.1 to better than 100 μm, than are routinely made at present in wavelength regions outside of the visible. Spectral data at high resolution could be obtained on the brighter stars, planets, and other sources. The instruments capable of performing polarization and accurate photometric measurements could be used to observe the zodiacal light and other nebular objects.

3. Summary

Table II-1 summarizes the above discussion of objectives, research areas, and measurement techniques.

Table II-1 Objectives, Research Areas, and Measurement Techniques

ASF Objectives	Research Areas	Measurement Techniques
Atmospheric Composition	Atmospheric Major and Minor Constituents Aerosols Airglow Aurorae	IR Interferometry UV/Visible Spectroscopy *In-situ* Measurements Polarimetry LIDAR
Atmospheric Processes	Vertical Profiles and Surface Distributions of Atmospheric Constituents Thermal Structure Optical Depth Airglow, Auroral, and Cloud Morphology Aerosols	IR Interferometry Solar and Stellar Occultation in UV and Visible Horizon Scans of IR Emissions Absolute Photometry of Reflected Solar Radiation LIDAR Measurements of Neutral Density and Aerosols Photographic and Video Imagery
Atmospheric Processes	Tropospheric and Stratospheric Pollution Ionospheric Absorption of Solar XUV and UV Radiation Ionospheric Seasonal and Diurnal Variations Airglow and Auroral Chemistry and Photochemistry Aerosol Formation and Dissolution	Mapping Distributions with UV/Visible Spectroscopy, Photometry; IR Interferometry; Polarimetry Absolute Solar XUV/UV Spectrophotometry *In-situ* Measurements Day/Night Variations Across Terminator
Atmospheric Dynamics	Major and Minor Constituent Transport Modes Aerosol Dispersal Atmospheric and Magnetic Interactions-Auroral Effects Velocities and Temperatures of Emitting Species	Spatial and Temporal Variations of Several Types of Data UV/Visible/IR Line Profile Analyses *In-situ* Measurements and Correlations of Data High Spectral Resolution Fabry-Perot Interferometry
Radiation Budget	Solar Input: Total Energy and Spectral Distribution Scattered and Emitted Energy Atmospheric Transmission Water Vapor and Temperature Profiles	Pyrheliometry Low Spectral Resolution Solar Spectrophotometry UV/Visible/IR Radiometry Multispectral Observations of *"Truth Site"* Light Sources IR Line Profile Analyses of CO_2 and H_2O Bands
Atmospheric Pollution	Concentrations and Distributions of Lower Atmospheric and Stratospheric Species	High-Resolution IR Interferometry Laser Backscatter and Absorption Spectroscopy
Earth Observations	Atmospheric Optical Depth Specrral Characteristics of Surface Features Meteorology	Absolute Photometry of Reflected Solar Radiation UV/Visible/NIR Spectroscopy IR Interferometry, Radiometry Photographic and Video Imagery
Astronomy	Cometary, Planetary Spectroscopy Stellar Spectroscopy Nebular Spectroscopy	UV/Visible/NIR Spectroscopy High-Resolution IR Interferometry

E. EXPERIMENTS TO ACCOMPLISH THE OBJECTIVES

Along with a definition of objectives for the ASF, the scientific community was requested to submit specific experiments and experimental design requirements that were considered necessary to accomplish the stated objectives. An analysis of the suggested experiments was performed to define: (1) to what major scientific objective they contribute and (2) what requirements on instrument, spacecraft, and mission design they impose. Six wavelength regions are represented: (1) the XUV--300 to 1250 Å, (2) the far ultraviolet (FUV)--1250 to 3500 Å, (3) the visible/near infrared (VIS/NIR)--3500 to 10,000 Å, (4) short wavelength infrared (SWIR)--1 to 5 μm (micrometers), (5) the long wavelength infrared (LWIR)--5 to 15 μm.

1. Description of Analyses

Experiments versus wavelength region are compared in Fig. II-2. It is apparent from the figure that the experiments are distributed fairly uniformly with respect to wavelength region; except for the far infrared, which shows a significantly lower number of experiments. However, this should not be interpreted as lower importance because the far IR experiments concern at least two important research areas--aerosols and the Earth's radiation budget. It can be concluded that ASF instrumentation should cover the entire wavelength region from 300 Å to 150 μm to properly address the identified science objectives.

The experiments were then analyzed for the requirements they imposed on ASF instrumentation. The parameters considered were: (1) spectral range, (2) spectral resolution, (3) radiance level, (4) field of view, (5) pointing requirements, and (6) desired orbit. Table II-2 presents a complete summary of science objectives, research areas, experiments, and experimental design parameters. In a number of cases, the parameters for the experiment were not appropriate for the column headings outlined above. Where necessary, important design parameters for those experiments were included in the comments column at the right of the table.

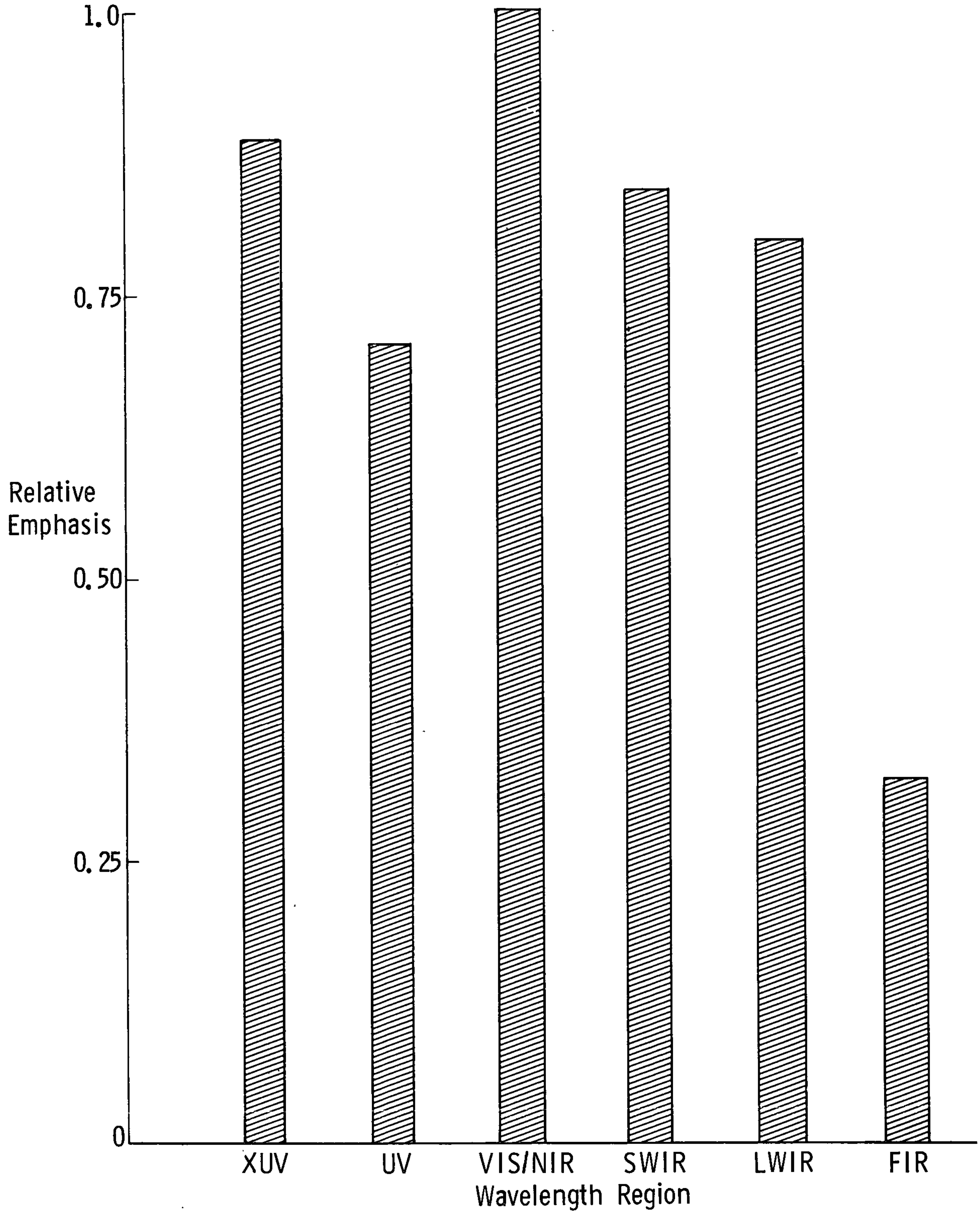

Fig. II-20 Experiments versus Wavelength Region

Table II-2 Detailed Summary of Objectives, Research Areas, Experiments, and Parameters

OBJECTIVE	RESEARCH AREA	EXPERIMENT	WAVE LENGTH	SPECTRAL RESOLUTION	RADIANCE	FIELD OF VIEW	POINTING	ORBIT INCLINATION	COMMENTS
Atmospheric Composition	Major and Minor Constituents	UV/Visible Spectroscopy						>55°	
		Nitric Oxide	2150 Å	10 Å	10 kR				
		Molecular Oxygen	2850 Å	20 Å	0.5 kR				
		N_2 Second Positive	3371 Å	10 Å	19 kR				
		Tropical Oxygen	1304 Å 1356 Å	10 Å 10 Å	4 - 7 R 50 - 350 R				
		General Survey Minor Constituents	3500 - 10,000 Å	10 Å					
		Nitric Oxide Continuum	3500 - 10,000 Å	10 Å	1 R/Å	1°	3 arc min		Nadir to limb scan
		Ozone Emissions							
		Carbon Dioxide Emissions							
		Atomic Oxygen Emissions							
		Metal Oxide Emissions							
		IR Interferometry	1 - 15 μm	0.1 cm^{-1}	10^{-11} W cm^{-2} sr^{-1} μm^{-1}			55°	Experiment also requires 3500 to 10,000 Å regions Note: the resolution for this radiance is 5 cm^{-1}
		Nitric Oxide							
		Hydroxyl							
		Ozone							
		Carbon Dioxide							
		Atomic Oxygen							
		Pollutants		0.25 cm^{-1}					
		In Situ Measurements							Refer to atmospheric and magnetospheric interactions, *in situ* experiments
		LIDAR	5800 Å	1 Å		30 arc min		Polar	2 Joule per pulse laser
		Measure Intensity of Scattered Sunlight	3914 Å 5577 Å 7000 Å	10 Å	400 MR 536 MR 870 MR	2 arc min	3 arc min		
		Polarimetry	2500 - 3500 Å	100 - 300 Å	10^2 - 10^3 MR	2 arc min	2 arc min		
Atmospheric Structure	Vertical Profiles and Surface Distributions	Solar Occultations	300 - 1800 Å	2 Å	12 MR	1°			
		Stellar Occultations	1200 - 7000 Å	10 Å					
	Thermal Structure	Horizon Scans				3 arc min	3 arc min	55°	
		Carbon Dioxide	2.7 μm 4.3 μm 14.5 - 15.5 μm 14 - 16 μm	50 cm^{-1} 50 cm^{-1} 1 μm 2 μm	10^{-6} w cm^{-2} sr^{-1} cm^{-1}				
		Water Vapor	6.3 μm	50 cm^{-1}	10^{-7} w cm^{-2} sr^{-1} cm^{-1}				
		Ozone	9.3 μm						
		Hydroxyl	3.3 μm						
		Nitrogen Oxides							
		Oxygen Temperature, Density, Vertical Distribution, Atomic O	1450 - 1950 Å	0.1 Å		6 arc min			
		Horizon Scans of CO_2 and H_2O	5 - 15 μm	5 cm^{-1}	10^{-5} w cm^{-2} sr^{-1} cm^{-1}	2 arc min			
	Optical Depth	Absolute Photometry of Reflected Solar Radiation	4000 - 10,000 Å	150 Å	0.1 - 0.2 w cm^{-2} μm^{-1}	3 arc min	3 arc min		
	Airglow, Auroral and Cloud Morphology	Photographic and Video Imagery	2000 - 8000 Å			30°			
	Airglow	Lyman Beta Emission	1026 Å	1 Å	5 R	10°	3°		
		Helium Emissions	304 Å 584 Å	10 Å	1 R 2 R				
		Oxygen	811 Å 834 Å 878 Å 910 Å 989 Å 999 Å 1027 Å		5 R 100 R 900 R 360 R 70 R				
		Nitrogen Emissions	800 - 1000 Å		2 kR				
		Tropical Oxygen	900 - 910 Å		50 R				
		General Survey	300 - 1250 Å						
		Specific Emissions	300 - 1250 Å		≥0.1 R				General survey will determine specific emissions to be observed.
		Predawn Enhancements of Airglow	800 - 1000 Å	10 Å	5 R	6°	1°		
Atmospheric Processes	Solar Ionospheric Absorption	Absolute Solar XUV/UV Spectrophotometry	300 - 1800 Å	2 Å	≥12 mR 12 x 10^6 R	1°			Absolute accuracy ±5% Relative accuracy ±1% Orbital calibration required
		Solar XUV Line Profile Measurements	300 - 1800 Å	0.02 Å		1°			
	Ionospheric Temporal Variations	Temporal Variations in Airglow Emissions and *in situ* Measurements							
		Day/Night Variation Across Terminator							
	Airglow & Auroral Chemistry & Photochemistry	Interpretations of Data from *in situ* Measurements and Optical Emissions							See applicable airglow and research areas
	Thermal Balance of Upper Atmosphere	Far IR Oxygen Emission Lines	62 μm 147 μm	1 cm^{-1} 1 cm^{-1}	4.5 x 10^{-10} w cm^{-2} sr^{-1} 4 x 10^{-11} w cm^{-2} sr^{-1}	3 arc min 3 arc min		55° 55°	

Table II-2 (cont)

OBJECTIVE	RESEARCH AREA	EXPERIMENT	WAVE LENGTH	SPECTRAL RESOLUTION	RADIANCE	FIELD OF VIEW	POINTING	ORBIT INCLINATION	COMMENTS
Atmospheric Dynamics	Constituent Transport Modes	Spatial and Temporal Variations in Data							
	Atmospheric and Magnetospheric Interactions	*In situ* Measurements							
		Neutral Mass Spectrometer							Mass range: 1 - 110 amu; Resolution: 1 amu; Pressure: up to 10^{-4} torr
		Ion Mass Spectrometer							Mass range: 1 - 36 amu; Resolution: 1 amu; Sweep time: 5 sec
		Ion Trap							Dynamic range: 5 to 5 x 10^6 ions/cm^3
		Electrostatic Probe							Electron temperature: 300° - 10,000°K; Electron density: 10^2 - 2 x 10^6 cm^{-3}
		Photoelectron Spectrometer							Energy ranges: 2 - 100 eV, 50 - 30,000 eV, 20 - 2000 keV
		Energetic Particle Detector							Energy range: 1 keV to 1 MeV; Angular Resolution: 10°
		AC and DC Magnetometer							Sensitivity: 1 gamma; Frequency response: 5 Hz; Accuracy: 0.1%
		Electrostatic Energy Analyzer							
	Auroral Effects	General Survey	300 - 1250 Å	10 Å	1 to 10,000 R	1°			Purpose of survey is to discover unknown auroral emission lines
		General Survey	1250 - 3500 Å		5 R				
		General Survey	3500 - 10,000 Å	20 Å		1°			
		General Survey	1 - 5 µm	0.25 µm		10 arc min			
		General Survey	5 - 15 µm	5 cm^{-1}		3 arc min			
		General Survey	15 - 150 µm	5 cm^{-1}					
		Nitrogen, Molecular	2100 - 2600 Å	10 Å	5 kR	1°			Lyman-Birge-Hopfeld
		Nitrogen Second Positive	3371 Å		19 kR				
		Nitrogen First Negative	3914 Å	10 Å	20 kR				
		Atomic Oxygen	5577 Å		13 kR				
		Auroral Mapping	Visible Photography						
		High Energy Particle Counters							See photoelectron spectrometer and energetic particle detector
		Magnetometers							See AC and DC magnetometer
	Velocities and Temperatures of Emitting Species	High Spectral Resolution Fabry-Perot Interferometry	1216 - 6300 Å	0.01 Å	1 - 10 kR	1 arc min	~1 arc min	Polar	
		In situ Measurements							See ion trap, electrostatic probe, photoelectron spectrometer, and electrostatic energy analyzer.
Radiation Budget	Solar Energy	Measure Total Energy Input - Pyroheliometer	0.2 - 50 µm	Total Range	135 mw cm^{-2}	5°	30 min	-55°	
		Measure Spectral Distribution - Low Resolution Solar Spectrophotometer	0.3 - 4 µm	0.003 to 0.04 µm	1 - 210 mw cm^{-2} $µm^{-1}$	1°			
	Cloud and Terrain Bidirectional Reflectance	Radiometry of Reflected Solar Energy	0.3 - 3 µm			3 arc min	3 arc min		
		Radiometry of Emitted Infra Red Energy	1 - 50 µm	5 cm^{-1}		3 arc min			
	Atmospheric Trausmission	Aerosol Effects on Transmission	3 - 5 µm 8 - 14 µm 16 - 18 µm	5 cm^{-1} 5 cm^{-1} 5 cm^{-1}	10^{-6} w cm^{-2} sr^{-1} 0.1 - 10 w cm^{-2} sr^{-1} 5 x 10^{-6} w cm^{-2} sr^{-1}	30 arc min			
	Optical Depth	Absolute Photometry of Reflected Solar Radiation	0.3 - 1.5 µm	0.005 µm	3 - 210 mw cm^{-2} $µm^{-1}$	3 arc min			
	Water Vapor and Temperature Profiles	IR Line Profile Analysis of CO_2 and H_2O Bands	5 - 15 cm^{-1}	1 cm^{-1}	10^{-6} w cm^{-2} sr^{-1}	3 arc min			
Atmospheric Pollution	Concentrations and Distributions	High Resolution IR Interferometry	1 - 5 µm	0.25 µm	10^{-11} w cm^{-2} sr^{-1} $µm^{-1}$	3 arc min			
	Trace Speices	Laser Absorption Spectroscopy							
		Active: Slave Satellite							
		Passive: Raman Backscatter							
Earth Observations	Spectral Characteristics of Surface Features	UV/Visible NIR Spectroscopy	1100 - 10,000 Å	1 Å	10^{-7} w cm^{-2} sr^{-1} cm	3 arc min			
		IR Interferometry, Radiometry	1 - 25 µm	5 cm^{-1}		3 arc min			
	Meteorology	Photographic and Video Imagery	0.35 - 1 µm	0.1 µm					See water vapor and temperature profiles
		IR Line Profile Analysis of CO_2 and H_2O Bands	1 - 20 µm	5 cm^{-1}	10^{-7} w cm^{-2} sr^{-1} cm^{-1}	30 arc min			
Astronomy	Solar Survey	High Spectral Resolution	300 - 1800 Å 15 - 150 µm	0.02 Å 50 cm^{-1}		1°			
	Planetary and Cometary	High Resolution Spectroscopy	1150 - 10,000 Å	0.1 - 1 Å	2 - 20 kR				
	Zodiacal Light	Spectrophotometry and Polarimetry	15 - 150 µm 3500 - 7000 Å	1 cm^{-1}	to 10^{-3} of solar coronal brightness				
	Nebular	Molecular Hydrogen in Galactic Plane	28 µm						

2. Experiment Areas Requiring Further Definition

Some experiment areas have major gaps in the experiment definition, and thereby require the maximum definition effort in following program phases. Those experiment areas are outlined in the following paragraphs along with the current state of definition and some suggested experiments.

a. *Earth Radiation Budget* - The estimations of the Earth's radiation budget have been made from measurements by instrumentation that were not designed for this purpose. As a result, the data have not been of good quality; the study is in its very early stages. For example, the solar constant has only been accurately measured in the last few years and has not been monitored for stability over an 11-year solar cycle. The design of the first space experiment to accurately measure the radiation budget is currently taking place for a 1974 flight on the NIMBUS satellite.

Because these efforts are only just beginning, the definition of an ASF radiation budget experiment is lacking in many details. Maintaining a stable calibration over time spans of several years is an essential requirement, and one role envisioned for ASF would be to periodically fly a set of detectors that would be used to verify the calibration of unmanned satellite experiments in orbit. The ability of the Shuttle to return ASF instruments to the ground for recalibration and reflight is an important consideration. Final specification of the wavelengths and spectral bandwidths of the observations must await the results of the NIMBUS radiation budget experiment.

Because of the short duration of Shuttle sortie flights, it is not anticipated that the ASF would be able to gather a significant portion of the data necessary to continuously monitor the global radiation balance. However, the ability to select the orbit and direct the instruments to the area where detailed observations are desired would enable the ASF to fill in areas where data from the operational satellite system is deficient in quantity, or of questionable quality. For high spatial resolution measurements of surface features, and the effects of specific meteorological features such as high cirrus cloud sheets, weather front systems, hurricanes, etc, the ability of the ASF scientist to direct his instruments to targets of interest is an invaluable advantage of a manned platform. A specific list of targets, scan patterns, resolutions, and other observational requirements would be premature at this time.

b. Meteorology - In addition to the experiments in Table II-2, further definition is required in the various distinct experiment areas of meteorology, such as:

1) Meteorology of the upper atmosphere,

    a) Detect and map noctilucent clouds in the atmosphere,

    b) Determine composition of these clouds;

2) Mesoscale meteorology weather patterns (2 to 12 hr in duration;

3) Air pollution - Meteorological effects,

    a) Map and detect gaseous and particulate pollutants,

    b) Correlate pollutants with weather modification and climate change;

4) Weather modification experiments,

    a) Monitor atmosphere before, during, and after modification activities (e.g., seeding),

    b) Locate areas for test;

5) Optical properties of clouds,

    a) Water, ice clouds (determining albedo),

    b) Measuring size, height and thickness of clouds,

    c) Determining nature of particles in clouds;

6) Stratosphere,

    a) Composition,

    b) Radiative properties,

    c) Baseline information to be used in monitoring supersonic transport atmospheric effects;

7) High-resolution stereo cloud photography.

c. Lidar - Further definition is required of the experiments that might be performed by Lidar systems on the ASF mission. The experiments suggested to date may be divided into three general categories:

1) Radiation budget experiments;

2) Synoptic meteorology;

3) Aeronomy

Radiation Budget - The radiation budget experiments divide into four subcategories:

1) Surface and/or Cloud Reflectivities - A lidar operated in a downward looking configuration could be used to determine surface reflectivities of the earth (ocean, ground) and cloud top reflectivities. This measurement may be desirable at several wave lengths and angles other than the vertical. These data are required to determine the albedos required for global heat budget determinations, either directly or in terms suitable for a parameterized model. This measurement would also yield spacecraft height.

2) Atmospheric Transmission - A lidar operated in a downward looking vertical and off-vertical configuration, at a single wavelength, could provide height resolved measurements of transmission. The procedure can be extended to several wavelengths to provide the wavelength variation of the transmission function. These data are also required in the computation of global radiation balance and heat budget. They could presumably also be parameterized to provide an average description of maritime and continental values.

3) Stratospheric Particulate Monitoring - Particulates in the stratosphere may be detected by the downward looking lidar. The excess scattering (over and above a molecular atmosphere) is detected. The backscattering information is of importance in radiation modeling, but its greatest immediate application may be in monitoring particulate pollution due to the operation of aircraft in the stratosphere. Scattering from tropospheric particulates is, at the present time, too difficult to interpret quantitatively in terms of the physical parameters describing the aerosol.

4) Cloud Top Measurement - The distance from the ASF to cloud tops is easily measured by lidar. This information could be of use to those investigating large-scale convective storms.

Synoptic Meterology

Temperature Profiles - Processing of data obtained from experiments on atmospheric transmission could be used to obtain thermodynamic state variables of the troposphere and stratosphere. The method relies on lidar signals obtained at two or more wavelengths (one of which may be a return that has been Raman shifted by an atmospheric constituent), propagated vertically and at some angle from the vertical. These data could well be the most valuable obtained from the ASF lidar, in that they lend themselves directly to use in synoptic meteorology.

Unlike the passive remote sensing method, the short laser pulse is capable of providing a differential profile of the atmosphere. A well-calibrated multiple-wave length lidar can provide data for separating the concentration of particulates (aerosols) from molecular concentrations along the path of the interrogating beam.

In particular, pressure structure data acquired from such an instrument system operated in orbit could be capable of providing atmospheric circulation information up to an altitude of about 100 km. Changes in speed and position of the jetstream can be observed nearly as rapidly as they occur. Stratospheric warming events can be located and tracked. Accurate data can be provided for numerical weather prediction calculations.

A lidar installation on or released from ASF would provide an entirely new approach to the exploration of the circulation and dynamics of the upper stratosphere and mesosphere. A system of three such installations, equidistant and in the same polar orbit, would provide the proper grid scale for global forecasting. The potential of the ASF lidar system as a tool for investigation of the meteorology of the atmosphere is outstanding and should certainly be explored.

Ozone Distribution - The distribution of ozone could be mapped both vertically and, of course, horizontally. The vertical distribution profiles could be obtained by interrogating both inside and outside of an ozone absorption band in the ultraviolet.

Subproblems whose solutions may be accelerated by these measurements are those dealing with ozone transport. Of special interest would be the somewhat anomalous transport associated with stratospheric warmings. The potential destruction of ozone by effluents from stratospheric aircraft and the consequent biological damage make it mandatory that such effluents be brought under surveillance.

Aeronomy

Noctilucent Cloud Studies - Noctilucent clouds, when they exist, would be routinely interrogated by the lidar. The information would be obtained from the backscattering signature. This method would permit much more extensive investigation than the visual techniques now in use.

Nacreous Clouds - The procedure for investigating nacreous clouds would be similar to that discussed under noctilucent clouds.

Oxygen-Nitrogen Mixing Ratios - the O_2/N_2 mixing ratios in the upper stratosphere and mesosphere could be amenable to determination by measurements of total Rayleigh scattering and N_2 Raman scattering.

Alkali Metals at 90 km - The sodium layer at 90 km has been investigated by the passive twilight method and by ground based lidar employing resonance scattering at 5896 Å. With suitable tuning, this technique could be exploited for the investigation of potassium (7665 Å) and perhaps lithium (6708 Å). The results would include density profiles and mixing ratios of these constituents.

Estraterrestrial Aerosol Flux - An influx of extraterrestrial dust can best be detected in a region where molecular scattering does not overwhelm the scattering from the dust. Deceleration and slowing, leading to stratification, must also occur. The 70 to 90 km region satisfies these requirements and would be amenable to lidar sounding from the ASF.

d. *Polarimetry* - Scattering of incident sunlight by the gas in the atmosphere is mainly Rayleigh scattering, as long as the wavelength of interest is not near an absorption band. Rayleigh scattering is polarized in a well-known way and knowledge of the polarization *per se* is not of much interest. Aerosols, on the other hand, are generally Mie scatterers, whose polarization as a function of wavelength, geometry, and aerosol characteristics is quite complicated. Detailed spectropolarimetry could thus contribute to a statistical knowledge of aerosol characteristics, such as particle size distribution and refractive indices.

The effective polarization of light scattered by aerosols is less than that scattered by a gas. A crude measure of the integrated aerosol concentration along the line of sight could thus be derived by comparing the observed polarization with that expected from a Rayleigh scattering atmosphere. The length of the path over which the integration is performed could be varied if the measurements are made in the ultraviolet, where ozone attenuates the incident (and scattered) radiation as a function of altitude. For aerosol height profiling, wavelengths from 2500 to 3400 Å would be appropriate. Height profiling in the UV would require an instrument with a dynamic range on the order of 10^4 and fairly high spectral resolution, because the absorption varies with wavelength.

Fractional polarization needs to be measured to better than 0.1%, the direction of the polarization vector to better than 2 deg, and the wavelength resolution required would be about 100 Å, or better. Special attention would be necessary to nullify the effects of residual intrinsic polarization in the polarimetric instrument.

e. *In-Situ Measurements* - Although the general type of measurements to be performed and a tentative list of instrumentation for *in-situ* measurements have been determined, no specific set of objectives has been formulated to which this type of observation should be directed. The scientific questions to be perused must be compatible with the orbits and mission durations of which the Shuttle would be capable. The ability of the Shuttle to provide a much greater variety of optical measurements than can any other vehicle on which *in-situ* probes have flown is another factor that must be considered in mission planning. Because of the time lag between the current ASF definition work and the flight time for an integrated atmospheric science Shuttle payload, it is difficult to do meaningful mission planning at present.

f. *Auroral Observations* - Precise definition of the auroral observation requirements for ASF has not been achieved, although an independent study has been completed that defines auroral scientific objectives, and gives some information on the types of observations and instrumentation that would be required. A

NASA inter-center organization known as the Atmospheric and Space Physics Working Group, in its July 31 - August 4, 1972, meeting recommended, however, that the objectives of the ASF and a proposed Shuttle Auroral Observatory be combined into an Atmospheric and Auroral Science Facility (AASF). Additional study efforts in this area will be forthcoming, and are expected to provide adequate definition of experimental requirements.

F. OBSERVATIONAL REQUIREMENTS AND CONSTRAINTS

In addition to material on objectives, experiments, and experimental parameters, the scientific community was asked to identify other requirements for the successful completion of their experiments. The responses lead to the definition of three observational requirements for the ASF and identified some constraints associated with the Shuttle Program.

1. Observational Requirements

It was definitely established during the science objectives study that the ASF must be able to acquire simultaneous measurements over a wide spectral range. Several instruments must be available to cover the range, therefore. Implementation of this requirement would involve a boresighted cluster of instruments on a pointable gimbal mount, and, because of the bulk of such a cluster, a remote video display of the common field of view to the ASF crew would be required.

Of equal importance to the simultaneity requirement for atmospheric observations was the requirement for simultaneous absolute measurements of the incident solar radiation in both its total energy input and in its spectral distribution. Several instruments would be necessary to implement this requirement, and they would have to be mounted independent of the atmospheric instruments.

A third requirement to be derived from the scientist responses was the importance of an independent previewing capability for acquisition of upcoming targets and for searches for transient features. To provide this capability, a third gimbal mount would be necessary. Table II-3 summarizes these significant observational requirements.

Table II-3 Observational Requirements Derived from Experiments

Simultaneous Spectral Observations of Atmospheric Features
Several Instruments to Cover Required Spectral Range
Instruments Boresighted to Same Field of View
On-Line Video Display of Field to ASF Crew
Simultaneous Monitoring of Solar Flux in Support of Atmospheric Observations
UV to IR Total Absolute Solar Irradiance
UV to IR Low Resolution, Absolute Intensity Measurements
XUV and UV Moderate Resolution, Absolute Intensity Measurements
XUV and UV High Resolution, Relative Intensity, Line Profile Measurements
Previewing System
Wide Field of View Acquisition of Upcoming Features
Search for Transient Features

2. Shuttle Program Constraints

Because the Space Shuttle is the vehicle on which the ASF would operate, it is important to identify at an early stage the unique features of the Shuttle Program that will act to constrain the ASF in the accomplishment of its objectives. These constraints arise principally in two areas: (1) limitations in Shuttle/payload accommodations and (2) limitations associated with the mission or orbital characteristics.

a. Shuttle Payload Accommodations - The following list is neither exhaustive nor necessarily the final word on any of the items. However, all of the items bear watching as the Shuttle Program develops; in some cases, the ASF (as a user of the Shuttle) should strive to effect changes in the proper directions.

Thermal Protective System (TPS) - The aim is to produce a fully reusable outer surface for the Orbiter. A ceramic material has been suggested, but an ablative material may be used as a backup, or the early vehicle may have an entirely ablative surface with its consequent outgassing disadvantages.

Pointing - The Shuttle proposed pointing system involves six 25-lb hydrazine thrusters capable of providing a pointing stability of from 5 to 30 arc sec. The system would provide absolute pointing information at the Orbiter navigation base of 10 arc sec accuracy, and the problems of translating this information to the location of the payload instruments are being studied. An alternative system that alleviates the reaction products of the thrusters controls the Orbiter pointing by control moment gyros located in the payload bay.

Electric Power - The following capability is available to payloads: 30 vdc nominal; 1000 w average, with 1500 w peak during maximum Orbiter operations; 3000 w average, with 6000 w peak during on-orbit coast operations; 50 kwh nominal, with 1000 kwh available with additional tankage. This capability is undergoing review, however.

Avionics - The following communications and data handling capability is available to payloads: two-way voice intercom (Space Shuttle-Payload-EVA); conference voice (Ground-Space Shuttle-Payload, Attached or detached); low to medium digital data interface (Space Shuttle-Payload-Ground, 25 kbps dedicated, 256 kbps maximum); wideband analog data interface (Space Shuttle-Payload-Ground); low digital RF interface (Space Shuttle-Released Payload, 2 kbps); color television (Space Shuttle-Payload-Ground); caution and warning (Hardwire Space Shuttle-Payload); payload data processing (including Command, Control, and Monitor; 10,000 32-bit words reserved for payloads); and space allocation in Space Shuttle for dedicated displays and controls provided by payload.

Remote Manipulator System - For payloads to be retrieved from orbit, they must include their own capability for stabilization before retrieval. The Shuttle possesses no capability for retrieval of spinning payloads.

b. Orbital Limitations - A variety of constraints confronts the experimenter in Earth orbit. The items below illustrate some of the accommodations that must be made. For reference, typical orbital characteristics anticipated in the sortie missions are:

1) Altitude - 100 to 270 n mi (185 to 500 km), usually circular;

2) Speed - About 7.7 km/sec, little variation throughout altitude range;

3) Period - About 94 minutes at 270 n mi (500 km) altitude;

4) Inclination - Currently unconstrained.

The points summarized below must be considered when performing horizon observations:

Altitude n mi	Altitude km	Range to Horizon km	Scan to Reach 500 km, deg	2 km FOV arc min
100	185	1500	~18	~5
270	500	2400	~12	~3

Time has a major effect on observations from orbit as illustrated by the three items described below.

Occultation Observations - The rate at which the solar/stellar source moves through the atmosphere is shown in Fig. II-3. In one region of present interest ($\leq$200 km), the tangent point is plunging through the atmosphere at more than 2 km/sec, necessitating a high data rate to retain spatial information.

Earth Observations - Spatial resolution on the surface for observations in an inertial-pointing, survey mode degrade rapidly because of the rapid orbital motion, as illustrated:

Time, sec	Ground Smear, km
0.1	1
0.6	5
1.3	10
2.6	20
6.5	50
13.0	100

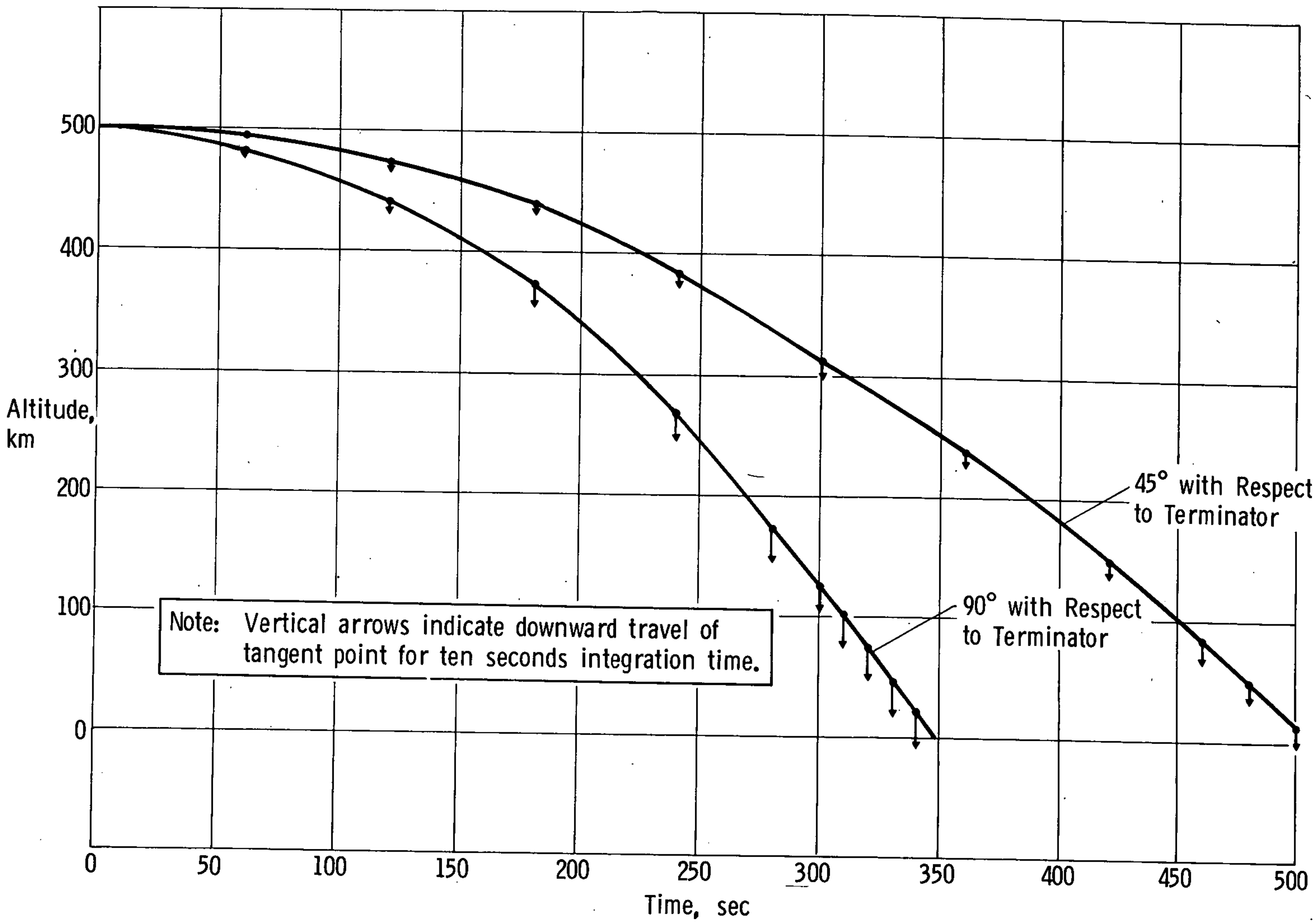

Fig. II-3 Vertical Motions for Solar/Stellar Occultation Experiment (500 km Orbit)

For observations of a specific point on the surface, the situation improves but is still restrictive. In the following tabulation, time is measured from the point at which the spacecraft is directly over the target, the angle is zenith angle, the spacecraft's direction relative to an observer on the ground target, and air mass is computed from the secant of the zenith angle.

Time, sec	185-km Orbit		500-km Orbit	
	Angle, deg	Air Mass	Angle, deg	Air Mass
5	11.7	1.02	4.3	1.00
10	22.6	1.08	8.6	1.01
20	39.9	1.30	16.9	1.04
50	65.8	2.44	37.7	1.26

If a variation of 10% in air mass is a tolerable limit, a maximum observation time of about 1 minute (2t) is available in a 500-km orbit.

Extraterrestrial Observations - Aside from solar work, extraterrestrial observations generally require long integration times for which Doppler spread due to orbital motion can be troublesome, especially in the near IR. The maximum spread resulting from motion in typical sortie orbits is as follows:

λ	1000 Å	1 μm (10^4 cm^{-1})	5 μm (2000 cm^{-1})	10 μm (1000 cm^{-1})
$\Delta\lambda$	0.05 Å	0.5 cm^{-1}	0.1 cm^{-1}	0.05 cm^{-1}

For high resolution work, orbital inclination and launch time must be carefully selected.

Finally, the inappropriateness of a low Earth orbit spacecraft for studying phenomena with variations on the order of hours is illustrated in Fig. II-4. Successive ground traces over the United States for a 55-deg inclination orbit are shown, along with several small circles that show approximate 111 km FOV for an EREP mapping camera. It would be a minimum of 12 hr, at best, before the spacecraft would pass over a particular point on the surface a second time.

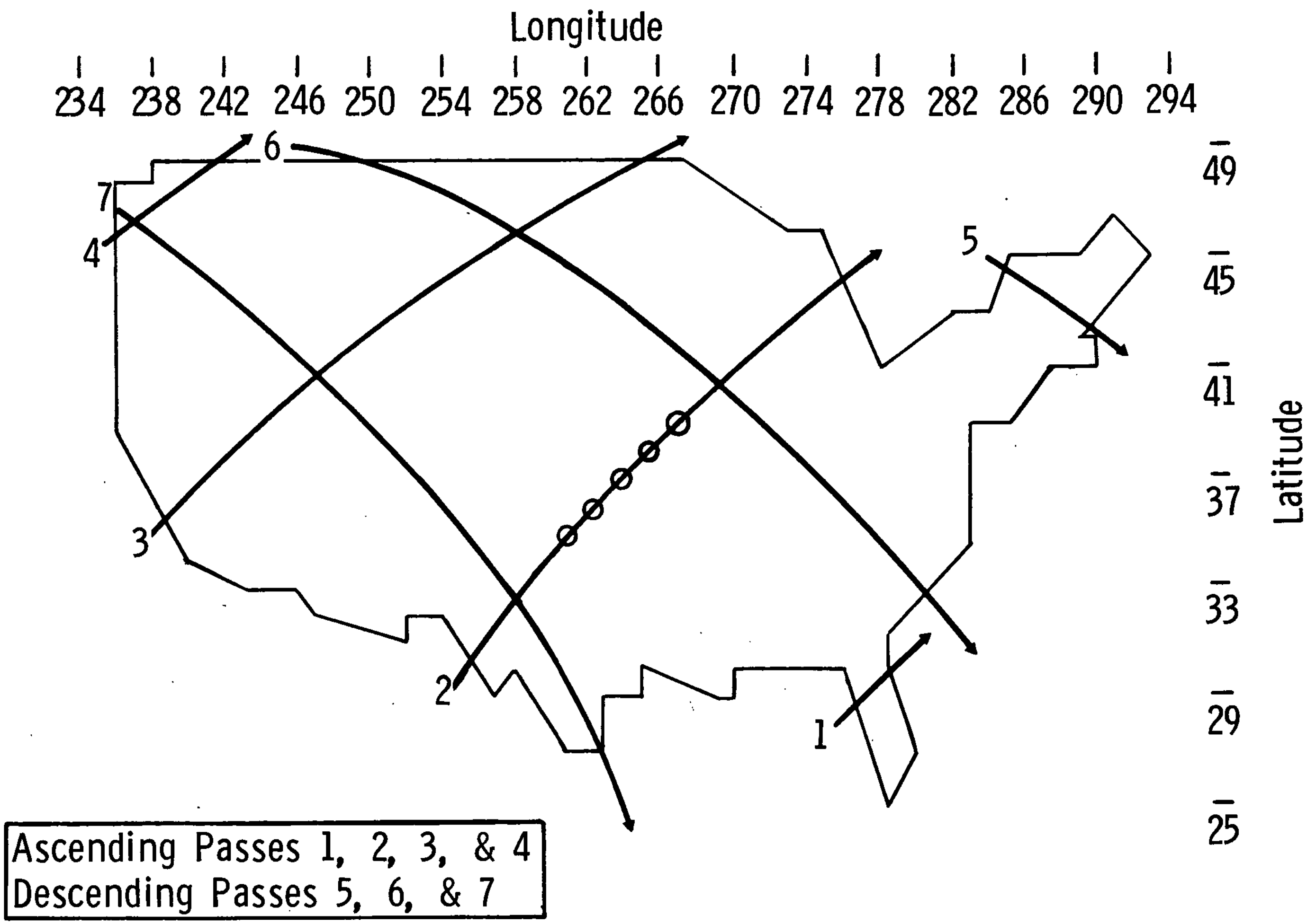

Fig. II-4 Successive Ground Traces

G. DESIGN REQUIREMENTS

A final analysis of the experiment requirements was performed to define the parameters driving instrument designs, i.e., the most stringent requirements on wavelength resolution, radiance levels, etc, that ASF instrumentation must meet. The discussion up to this point has placed no restrictions on experiments and design parameters that were suggested for the facility. Careful examination of the design parameters was necessary, however, to determine whether particularly severe or unique requirements were being placed on the ASF design by a small set of experiments. Experiments imposing those requirements were examined for their contributions to the objectives of the facility. In certain well-defined cases, experimental requirements were ignored in the preliminary design of ASF instrumentation.

A substantial number of experiments received were concerned with astronomical observations of "point" sources. The primary optical requirement of such observations is a large collection aperture. A distinct conflict arises with two requirements of a majority of the atmospheric experiments, namely, simultaneous observations with several instruments covering a wide spectral range, and short focal length (and small focal ratio) collectors that provide relatively wide fields of view of extended atmospheric sources. The atmospheric requirements can be met with small aperture telescopes, individually tailored to specific instruments, permitting the set of instruments and collectors to be boresighted in a gimballed cluster to provide simultaneous spectral coverage. Another result of the large aperture astronomy requirements is a sizeable focal length, even for a "fast" telescope. This produces a large image scale at the focal plane, and the pointing stability required to hold a stellar image on the entrance slit of a spectrometer, for example, is more than an order of magnitude greater than the stability required of the small aperture, short focal length telescopes of the type described above.

The impact on the design of an ASF including "point-source" astronomy is, therefore, twofold -- firstly, large apertures would be required to detect faint sources; secondly, the large aperture telescopes would force a much more stringent pointing requirement on the facility. For these reasons, the preliminary design of the ASF has proceeded without taking into account the requirements of "point-source" astronomy.

Some of the meteorological experiments required continuous (or very closely spaced) observations of developing weather phenomena, such as tornados, storm fronts, or simply normal cloud systems.

These events typically have development time scales on the order of hours. All such experiments suffer from the fundamental observational limitation imposed by the orbit in which the ASF would be constrained to move. As was discussed in Section II.F, a given point on the Earth's surface is available for useful observation for at most a couple of minutes before the orbiting ASF is too far away to continue. Furthermore, for all except very low inclination orbits, there may be a period of from 12 hr to several days before the ASF would reacquire the same point on the surface (see Fig. II-4). All experiments requiring lengthy observation time are, therefore, unsuited to the ASF in low Earth orbit, and their design requirements have been ignored in the preliminary design.

Table II-4 presents the driving experimental parameters for ASF instrumentation. They have been arranged in two major groups -- those relating to atmospheric observations, and those relating to solar observations. Within each major group there are parameters that have been identified with spectrometric, radiometric, or photographic types of observations, as well. In addition, for special-purpose observations requireing their own set of requirements, these parameters have been called out for clarity. The requirements that have been included in the table are wavelength range, wavelength resolution, wavelength precision, radiance level (minimum, maximum), radiometric accuracy (%), field of view, stray light rejection, observation time, and comments. Not all of the data in the table have been submitted by the scientific community. Where considered appropriate, data have been developed in-house to provide a more complete definition of requirements. Note that the ASF instrumentation would not necessarily be required to satisfy all driving parameters at once. Reference to specific experiments from which these parameters have been derived is important for understanding the actual observational conditions that must be simultaneously satisfied.

Table II-4 Driving Parameters for Instrument Design

OBSERVATION	PARAMETER	WAVE LENGTH RANGE	WAVE LENGTH RESOLUTION	WAVE LENGTH PRECISION	RADIANCE LEVEL MINIMUM	RADIANCE LEVEL MAXIMUM	RADIOMETRIC ACCURACY	FIELD OF VIEW	STRAY LIGHT REJECTION	OBSERVATION TIME	SPECTRAL PURITY	COMMENTS
Atmospheric	Spectrometric	300 – 1300 Å	10 Å	10 Å	0.1 R	10 kR		10°	10^4	2 min		
		1150 – 3500 Å	0.1 Å	0.1 Å	0.1 R	20 kR	10% rel	1 arc min	10^5	40 sec		99% spectral purity, Stokes parameters ±5%
		1216 – 6300 Å	0.01 Å		1 kR	10 kR						Fabry-Perot Interferometry
		3500 – 10,000 Å	10 Å	1.0 Å	1 R/Å	2 x 10^5 R/Å	5% rel	3 arc min	10^8	40 sec		99% spectral purity, Stokes parameters ±5%
		4000 – 10,000 Å	150 Å		0.1 w cm^{-2} μm^{-1}		2%	3 arc min				
		1 – 5 μm	0.05 cm^{-1}	0.025 cm^{-1}	10^{-11} w cm^{-2} sr^{-1} μm^{-1}	10^{-6} w cm^{-2} sr^{-1} cm^{-1}	5%	1 arc min	10^6	3 min		Minimum radiance levels for the 1-5, 5-15, and 15-150 μm bands correspond to 5 cm^{-1} resolution.
		5 – 15 μm	0.1 cm^{-1}	0.05 cm^{-1}	10^{-11} w cm^{-2} sr^{-1} μm^{-1}	10^{-6} w cm^{-2} sr^{-1} cm^{-1}	5%	1 arc min	10^5	3 min		
		15 – 150 μm	0.1 cm^{-1}	0.05 cm^{-1}	10^{-11} w cm^{-2} sr^{-1} μm^{-1}	10^{-6} w cm^{-2} sr^{-1} cm^{-1}	5%	1 arc min	10^5	3 min		
	Radiometric	1150 – 8000 Å	10 Å	5 Å	0.1 kR	30 kR	5%	1 arc min	10^8	0.1 – 0.5 sec		Selected emission lines
		2.7 – 16 μm	50 cm^{-1}	5 cm^{-1}	10^{-3} w cm^{-2} sr^{-1} μm^{-1}		10%	3 arc min	10^6			Selected emission lines
		62 μm	1 μm^{-1} μm^{-1}		4.5 x 10^{-10} w cm^{-2} sr^{-1} μm^{-1}		10%	3 arc min				
		147 μm	1 cm^{-1}		4 x 10^{-11} w cm^{-2} sr^{-1} μm^{-1}		10%	3 arc min				
	Photographic	2400 – 7000 Å						30°				
		3500 – 7000 Å						30°				
Solar	Spectrometric	180 – 1800 Å	2 Å	0.25 Å			1%	1°		10 min	<2%	
		300 – 1800 Å	0.02 Å	0.25 Å		2.7 x 10^{11} photons cm^{-2} sec		1°			<2%	
		1 – 15 μm	5 cm^{-1}		6000° Black Body			1°			<2%	
		15 – 150 μm	50 cm^{-1}		6000° Black Body			1°				
	Radiometric	0.3 – 4 μm	3 cm^{-1}	1.5 Å	0.001 w cm^{-2} μm^{-1}	0.21 w cm^{-2} μm^{-1}	5%	1°	50	3 min	<2%	
		0.2 – 50 μm			125 mw cm^{-2}	145 mw cm^{-2}	1%	5°	10^2	5 sec		

H. METHODS FOR FURTHER DEFINITION

The stated intention of the science objectives study and the preliminary design study has been to establish a set of research objectives and preliminary performance requirements for an ASF that would not become operational until the latter part of this decade. The obvious difficulty in determining what the important scientific questions will be at that time is well recognized, not to mention the performance requirements that could or should be placed on any instrumentation to achieve those objectives. In pursuing this study, the scientific community has had the burden of predicting the future placed upon it. Generally speaking, the responses received were descriptions of the individual scientist's own current research interest. The resulting set of objectives, experiments, and requirements is thus a reasonable statement of what an ASF should be addressing were it in existance today.

Using the present problems in atmospheric research as a basis for the development of a Shuttleborne ASF is at least a reasonable starting point. The point made at the recent review meeting in October 1972 at NASA-MSC for maintaining the objectives and requirements for the facility in a fluid state is an important one, and the point is well taken. The fact that a preliminary design study for an ASF is coming to a close does not mean that considerations of the objectives, and so forth, are over and settled. The definition of objectives and requirements must continue, with certain important points kept in mind, however. First, one is attempting to develop a complete payload for Shuttle from the ground up, so to speak. Second, with sufficient concerted effort, it is possible that an ASF may participate in some of the early development or checkout missions of Shuttle in, perhaps, 1978. After a lengthy computation, one realizes that in 5½ to 6 years the type of observations being discussed in this report may begin to take place, not simply with one instrument, but with an entire facility-1978 is not that far off. Finally, as has been mentioned before, the ASF would be expected to evolve throughout its useful lifetime. Returning to Earth at the end of each mission allows the ASF to be easily reconfigured. Therefore, one need not be forced to design for immortality.

Possible recommendations which might be made to effect a satisfactory compromise are the following: (1) continued dialogue with interested scientists on their interests and predictions; (2) regional discussions, similar in type to the October 1972 meeting, but sufficiently localized so that it is economically feasible for more scientists to attend; (3) the establishment of a recognized science advisory board, reflecting a broad range of interests in the atmosphere and related areas, which would function in a review capacity for ASF objectives and requirements; (4) a commitment within one to two years on the initial objectives, requirements, and instrument designs for the early version of the ASF; and (5) pursuit during this time of needed development in promising instrumental areas.

For additional discussion of this area, see Future Activity, Section VI.D.

III. IMPLEMENTATION APPROACH

Preliminary designs for Atmospheric Science Facility (ASF) instrumentation were performed to:

1) Illustrate the facility concept in terms of actual instruments;

2) Identify the scope of the design problem as to instrument size, numbers, and areas requiring development;

3) Lead to preliminary concepts for the overall ASF configuration;

4) Provide a solid basis for iteration in later phases of the program.

A. REVIEW OF CURRENT TECHNOLOGY

A review of existing or proposed instruments, instrument components, and collecting optics for atmospheric research and related fields showed that virtually all of the objectives derived in the study could be achieved with existing instrument design concepts. That is, the objectives considered by the scientific community to be of importance did not demand instruments far beyond the state of the art. Because one important concept for the facility was the attempt to accomplish as many of the objectives with as few general-purpose instruments as possible, the many potential instrument designs were evaluated with that in mind, and a baseline set of instrument types was identified for preliminary design. Specific details of that review are to be found in *Preliminary Design Study for an Atmospheric Science Facility, Midpoint Technical Report,* May 1972 (MCR-72-134).

B. ADDITIONAL INSTRUMENTATION FACTORS

In addition to a complete set of experimental design requirements described in Section II.E, and the driving design parameters presented in Section II.G, the preliminary design study of ASF instrumentation was influenced by a number of other factors. These effects range from basic concepts of the facility itself, to considerations of observational requirements (spectral, spatial, and timing requirements) and the interplay among several instruments. The net result was to cause the preliminary performance requirements to move toward certain types of instruments, and the aim of this part of the report is to provide a bridge between the specific design parameters of the previous sections and the preliminary performance requirements described below.

1. Observational Requirements

Not directly reflected in the individual experimental design parameters, but emphasized repeatedly at conferences and in correspondence with the scientific community are the three major observational requirements discussed in Section II.F. They are briefly to:

1) Acquire simultaneous atmospheric measurements over a wide spectral range;

2) Obtain simultaneous absolute measurements of incident solar radiation in both its total energy input and in its spectral distribution;

3) Provide the capability to independently acquire upcoming targets, and to search for transient features, giving threshold indications of desirable emissions for study.

2. Factors Common to All Instruments

A concept that has been with the ASF since its inception is that of general-purpose instrumentation. The principal thrust of the preliminary design study has been to identify the means whereby a maximum number of scientific objectives may be accomplished with as few general-purpose instruments as possible. As necessary, these instruments have been supplemented with additional, special-purpose instruments to accomplish the objectives reflected in the table of driving parameters for instrument design (Section II.G). In implementing the preliminary performance requirements to be set forth in Chapter IV of this report, the instrument designs should continue to embrace the general-purpose concept wherever possible.

In atmospheric studies, one observes spatially extended sources. Because the power entering an instrument from such sources is inversely proportional to the square of the focal ratio of the collecting optics, an ideal optical system is one that is optically fast, i.e., one that is characterized by a small focal ratio. The physical size of the collection aperture is of no significance--an important distinction between atmospheric and astronomic requirements. The size of the collection aperture is actually fixed by the field-of-view requirements of the experiment, which dictates the required image scale at the entrance aperture of the experiment's instrument. Image scale fixes the focal length of the collecting optics, and, thus, the aperture is fixed through the focal ratio (which is presumably matched to that of the instrument). As we will see later, the field-of-view requirements are such that the resulting sizes for collection optics are quite small, and considerably less than ideal for astronomical work.

The fact that the proposed vehicle on which the ASF should operate is the Space Shuttle has far-reaching effects on the ultimate designs of ASF instrumentation. The most influential factors are great payload weight and volume, potentially ample electric power, manned operations on-orbit, and a return of instrumentation to Earth-based laboratories. While some of the qualification requirements of space instrumentation will remain, it should be possible to go to simpler, more direct design approaches, greater weight and bulk, and greater operational flexibility in ASF instruments. A feature of immense potential is that of onboard calibration of instruments. Calibration sources and procedures of a size and complexity never before possible will become a routine feature of ASF operations. Finally, the do-or-die quality that characterizes instrumentation on other types of spacecraft will be absent from the ASF, which will not only experience an evolution in its instrument complement, but also will provide an excellent development platform for new observational techniques.

3. Wavelength Specific Factors

The variety of experiments suggested were frequently specific to a given spectral region. Because instrumentation must also accommodate to the characteristics of the spectrum, design goals for each major spectral region can be conveniently isolated.

a. XUV Design Goals (300 to 1300 Å) - For atmospheric sources, full spectrometric coverage of the entire spectral region at the highest possible sensitivity is the primary design goal. Spectral resolution is to be considered secondary for what is initially careful spectral survey work.

Monitoring of the absolute XUV solar flux incident on the upper atmosphere must be performed for the entire spectral region. Very high resolution solar line profile studies are to be performed, as well.

b. UV Design Goals (1150 to ∿4000 Å) - For atmospheric spectrometry, the design goal is to provide variable resolution, variable field of view, high sensitivity spectrometric coverage of the entire spectral region. The highest resolution requirement is in the 1150 to 2000 Å region (∿0.1 Å). Fields of view must range from less than an arc min to many degrees. For some applications, data rates of less than 1/sec at very high sensitivity are necessary.

Monitoring the absolute UV solar flux incident on the upper atmosphere must be performed for the region 1150 to 1800 Å. Similarly, very high resolution solar line profile studies are required in the same region. From approximately 2000 Å and longward into the infrared, both the total solar irradiance and its spectral intensity distribution must be monitored at high absolute intensity accuracy. High spectral resolution is not important for the latter measurements.

c. Vis/NIR Design Goals (∿3500 to 10,000 Å) - As in the UV, the design goal for atmospheric spectrometry is to provide variable resolution, variable field of view, high sensitivity coverage of the entire region. In some cases, high data rates (less than 1/sec) at high sensitivity are required, and also, very high resolution, high sensitivity atmospheric line profile studies must be performed.

d. IR Design Goals (1 to 150 μm) - For atmospheric spectrometry, the spectral region from 1 to ∿15 μm must be covered with variable resolution and field of view, and high sensitivity. The spectral region from 15 to 150 μm may be studied by reconfiguring the short wavelength instruments, i.e., it is not necessary to simultaneously cover the longer wavelengths along with Vis and UV coverage. Very high sensitivity is required at the longer wavelengths. The highest spectral resolution requirements occur at the shorter wavelengths. For some applications, high sensitivity and high data rates are required, and high absolute intensity accuracy is necessary throughout the IR.

C. INSTRUMENTATION NEEDS

The design goals and range of experimental design parameters suggest that the 300 Å to 150 μm spectral region could be covered with four general-purpose spectrometers that are capable of interchange of internal components.

1. Spectrometric

Because of the severity of the optical reflectivity problem in the region shortward of about 1150 Å, one instrument should be designed for this region. A second spectrometer design could cover the region from about 1150 Å to ∿1 μm, if adequate flexibility for interchange of internal components were designed into it. Two instruments could cover the infrared from 1 to 15 μm. The first would provide the high resolution required in the 1 to 5 μm region, while the second would have somewhat lower resolution capability and would be capable of being reconfigured to work at wavelengths out to 150 μm. Because of the low signal levels anticipated at the longer wavelengths and the problem of high instrumental background radiation, the long wavelength instrument would undoubtedly have to consider cryogenic cooling of its optical system.

2. Solar

Four types of solar instruments would probably be required to meet ASF objectives. First, the total, absolute solar irradiance must be monitored to 1% or better over the 0.2 to 5 μm region. Second, low resolution, absolute measurements of the spectral distribution of solar energy over the same spectral range would be required. A relatively simple spectrometer design could achieve this requirement. A third type of instrument to monitor extreme ultraviolet and vacuum ultraviolet fluxes to 5% or better absolute accuracy would actually be composed of several fixed wavelength and scanning monochromators that would cover the spectral range from 170 to 1800 Å. Finally, high resolution measurements of solar line profiles in the 300 to 1800 Å region would also be necessary. These latter measurements would require only relative intensity accuracy, and could probably be achieved with three instrument designs optimized to the optical reflectivity characteristics of the 300 to 600, 600 to 1200, and 1200 to 1800 Å spectral regions, respectively.

3. <u>Rapid Data Rates</u>

Additional instruments for the UV through the IR would be required to provide the capabilities of variable field of view, moderate-to-low spectral resolution, absolute calibration, high sensitivity, and high data rates for solar or stellar occultation observations; for other atmospheric observations requiring absolute intensity accuracy, high spatial resolution and sensitivity; and to provide threshold indications of atmospheric emissions desired for study by other techniques.

4. <u>Special-Purpose Needs</u>

The following highlight special-purpose applications that the ASF would also be capable of undertaking:

1) Very high resolution visible spectrometry - To provide high resolution, high sensitivity observations in the visible region of the spectrum of airglow and auroral emissions for the study of atmospheric motions.

2) Polarimetry - To contribute to an understanding of aerosol characteristics such as particle size distributions and refractive indices; to derive aerosol height profiles by comparing observed polarization with that expected from a Rayleigh scattering atmosphere in the 2500 to 3400 Å spectral region (where the attenuation varies strongly with wavelength); and to provide additional means for studying the characteristics of surface features.

3) Active systems - Potential applications exist for fixed frequency and tunable lasers in the visible and UV for such things as spatial distribution, time variation, and particle size distributions of aerosols; identification and distribution of natural and artificial pollutants; studies of nucleation processes; distribution and structure of tropospheric and noctilucent clouds; upper atmosphere chemistry; discrimination between ice crystals and water droplets at high altitudes; water temperature from inelastic backscatter at air/water interfaces and other oceanographic studies; single or double pass absorption spectroscopy with remote ASF subsatellites; and "truth site" calibration of atmospheric transmission.

4) *In-situ* measurements - To contribute additional useful information for atmospheric studies by measurements of ambient atmospheric particles and fields. Measurements could include the composition and energy distributions of neutral and electrically charged atmospheric species, as well as species outgassed from the Shuttle itself. Additional measurements of magnetic field strengths and variations, and sources of energy input in the form of photoelectrons, energetic particles, and solar extreme ultraviolet radiation are possible.

5) UV/Visible documentation cameras - To provide photographic documentation of observations made with other instruments and to provide wide field records for airglow, auroral, and lower atmosphere cloud morphology; or for mapping purposes of such things as ozone clouds.

6) Visual display of field of view - To provide a variable field of view display to the ASF crew of the common field of view of the ASF instrumentation, and to provide an independent, variable field of view display to the crew for previewing purposes.

IV. PRELIMINARY PERFORMANCE REQUIREMENTS

In this chapter, preliminary performance requirements derived for Atmospheric Science Facility (ASF) instrumentation are presented. Experimental requirements and design factors that suggest broad categories of instrument types have been reviewed in Chapter III, and the following material presents the results of the preliminary design study in the form of requirements for instrumentation within those broad categories. As much as possible, freedom for innovative designs that satisfy the requirements is encouraged. Further details on the illustrative preliminary instrument designs developed in this study are given in Appendix A.

Separate sections are provided to describe and document the efforts undertaken under Tasks II and III. These separate sections are devoted to instruments, and pointing and control.

A. INSTRUMENTS

The preliminary performance requirements for the ASF instruments are divided among three categories of instruments--those for general-purpose measurements, solar measurements, and special-purpose measurements

1. General-Purpose Measurements

The requirements for the four general-purpose instruments are presented here.

a. XUV Airglow Spectrometer - The major instrument design problem to be contronted is the low flux levels from the airglow sources to be observed. Low optical surface reflectivities and scattered light are additional complications. Low source radiances are more easily accommodated by specifying a broad spectral bandwidth and a wide field of view. A high throughput instrument is preferred to a conventional slit spectrometer design. The instrument performance requirements are tabulated.

Parameter	Requirement
Wavelength Range	300 to 1300 Å
Sensitivity	0.1 Rayleighs at 584 Å (1 sec integration time)
Dynamic Range	0.1 to 2000 Rayleighs
Signal/Noise	$\geq$ 4 (for minimum signal)
Spectral Resolution	$\Delta\lambda$ = 10 Å
Spectral Purity	$\leq$ 25% (for minimum signal)
Polarization	Instrument Response to Polarized Light Should be Measured
Calibration	Orbital Calibration Check using Solar Radiation
Scan Rate	One Complete Scan in $\leq$ 2 minutes
Field of View	10° Full Width
Off-Axis Rejection	10^{-4} at 15° off Instrument Axis

b. UV-Visible Near IR Spectrometer - The wavelength region from 1150 to 11,000 Å should be covered by one or more scanning monochromators. The study to this point has envisioned a single spectrometer with a provision for interchanging internal optics.

The instrument performance requirements are tabulated.

Parameter	Requirement
Wavelength Range	1150 Å - 1.1 μm
Wavelength Resolution	0.1 Å for $\lambda < 3000$ Å 0.3 Å for $\lambda \geq 3000$ Å
Wavelength Precision	0.1 Å for $\lambda < 3000$ Å 0.3 Å for $\lambda > 3000$ Å
Sensitivity	0.1 R (1 sec integration time)
Dyanmic Range	0.1 R to 10^9 R
Radiometric Precision	±10% Relative
Field of View	0.08 x 1.8 mrad to 12 x 44 mrad
Polarimetric Precision	
Fractional Polarization	±0.1%
Other Stokes Parameters	±5%
Spectrum Scan Time at Highest Resolution	40 sec
Off-Axis Light Rejection	10^8 at 30 arc min outside of nominal FOV
Spectral Purity	<1% Contamination from Wavelengths Outside of Nominal Passband

c. High Resolution Infrared - A major purpose of this instrument is to acquire high resolution spectrometric data in the 1 to 5 μm infrared spectral band.

The instrument performance requirements are tabulated.

Parameter	Requirement
Wavelength Range	1 to 5 μm
Sensitivity	10^{-11} w cm^{-2} sr^{-1} μm^{-1} (at 5 cm^{-1} resolution)
Signal/Noise Ratio	100/1 (for analytic spectroscopy)
Dynamic Range	10^6
Spectral Resolution	0.05 cm^{-1} (maximum)
Observation Time	$\leq$ 3 minutes
Field of View	Selectable on Command, 3, 5, 15, and 30 arc min and 1 and 5 deg
Off-Axis Rejection	10^6 minimum

d. Cryogenically Cooled Infrared - The purpose of this instrument is to acquire spectral emission data in the 5 to 150 μm band. Signal levels and background constraints require that the entire instrument, optics, detectors, and support members, be cooled to cryogenic temperatures. The instrument should have the capability to be configured to operate in any finite band within the 5 to 150 μm region by interchanging internal components before flight.

The requirement to cool the entire instrument dictates that its physical size must be as small as possible while maintaining the instrumental parameters. The instrument must maintain the design temperature for a mission duration of at least seven days. Choice of cryogen will be dicated by the wavelength region in which the instrument is operating and the desired sensitivity. It may be desirable to design the instrument for only one cryogen.

The performance requirements are tabulated.

Parameter	Requirement Configuration A	Configuration B	Configuration C
Wavelength	5 to 15 μm	15 to 50 μm	50 to 150 μm
Sensitivity (at 5 cm^{-1} resolution)	10^{-11} w cm^{-2} sr^{-1} μm^{-1}	10^{-11} w cm^{-2} sr^{-1} μm^{-1}	10^{-11} w cm^{-2} sr^{-1} μm^{-1}
Signal/Noise Ratio	100/1	TBD	TBD
Dynamic Range	10^5	10^5	10^5
Spectral Resolution (Maximum)	0.1 cm^{-1}	0.1 cm^{-1}	0.1 cm^{-1}
Observation Time	$\leq$ 3 Minutes		
Field of View	Selectable, on Command, 3, 5, 15, and 30 arc min and 1 and 5 deg		
Off-Axis Rejection	10^6 - 10^7 (30 arc min Outside Nominal FOV)		

2. Solar Measurements

The requirements for the solar instruments are divided into the two categories of total solar monitoring and XUV-UV flux monitoring.

a. *Total Solar Monitoring* -This area will be treated in terms of integrated radiance instruments and solar spectral distribution instruments.

Integrated Radiance - The precise monitoring of the total solar energy integrated over the major portion of the spectrum is the most fundamental measurement in determining the Earth's radiation budget. Adequate instrumentation for this purpose has already been designed for monitoring at the Earth's surface, but operation from within the Earth's atmosphere limits the accuracy that can be achieved. Operation in the space environment should not require an extensive modification of established instrument designs.

The performance requirements are tabulated.

Parameter	Requirement
Wavelength Range	0.2 to 50 μm
Radiometric Precision	$\leq$ 1% Absolute Accuracy
Dynamic Range	125 to 145 mw cm^{-2}
Polarization	Instrument Response to Polarized Light Should be Known
Calibration	In-Flight Calibration Accurate to $\leq$ 1% Absolute
Response Time	5 sec
Field of View	5 deg
Off-Axis Rejection	10^{-2} (at 10 deg off Instrument Axis)

Solar Spectral Distribution - A simple low dispersion spectrometer can satisfy the requirement to determine the spectral distribution of the solar energy over the wavelength range that includes the major part of the solar radiation, with the following requirements as tabulated.

Parameter	Requirement
Wavelength	0.25 to 4.0 μm
Sensitivity	0.001 w cm^{-2} μm^{-1}
Accuracy	$\leq$ 5% Absolute
Dynamic Range	0.001 to 0.21 w cm^{-2} μm^{-1}
Resolving Power	$\lambda/\Delta\lambda \geq 100$
Spectral Purity	< 2% of Light Outside of Bandpass
Polarization	Instrument Response to Polarized Light Should be Known
Calibration	In-Flight Calibration Accurate to $\leq$ 5%
Observation Time	3 min
Field of View	1 deg
Off-Axis Rejection	50 (at 10 deg off Instrument Axis)

b. XUV-UV Flux Monitoring - This area will be treated in terms of solar intensity monitors and high spectral resolution line profile spectrographs.

Solar XUV-UV Intensity Monitor - Accurate monitoring of the XUV-UV flux from the entire solar disk would require a set of monochromators optimized to each part of the wavelength range to be covered. A set of fixed wavelength monochromators would monitor principal solar lines, while a set with each unit scanning a small portion of the wavelength band would provide coverage of all of the lines in the band. The requirement of high absolute accuracy in the measurement of intensity must be met by calibrating the instrument in orbit with the aid of a premonochromator to provide a spectrally pure source and a stable reference detector that would not degrade in orbit.

The performance requirements are tabulated.

Parameter	Requirement
Wavelength Range	180 - 1800 Å
Sensitivity	1% Relative Accuracy in 0.25 sec.
Dynamic Range	L α, 270 x 10^9 photons cm^{-2} sec^{-1} Ne VIII (780 Å), 0.15 x 10^9 photons cm^{-2} sec^{-1}
Spectral Resolution	$\Delta\lambda \approx 2$ Å
Spectral Purity	< 2% of Radiation Out of Band
Polarization	Instrument Response to Polarized Light Should be Known
Calibration	$\leq$5% Absolute (Orbital Calibration Uses Premonochromator and Reference Detector)
Observation Time	10 min Full Scan
Field of View	7 arc min (Along Dispersion Direction) 32 arc min (Normal to Dispersion Direction)

High Spectral Resolution Line Profile Spectrographs - This area will be treated in terms of three spectral ranges--300 to 600 Å, 580 to 1220, and 1150 to 1800 Å wavelengths.

300 to 600 Å Wavelength Range - Low flux levels and grating reflectivities force a grazing incidence spectrograph design for this wavelength range. The high spectral resolution is facilitated by working in a high spectral order. Long wavelength light is suppressed by a thin aluminum filter placed at the entrance slit. Stray light suppression still remains as the principal problem area limiting the intensity of the faintest lines that can be detected.

The performance requirements are tabulated.

Parameter	Requirement
Wavelength	300 to 600 Å
Sensitivity	Optimize with Respect to Background Signal Level from Scattered Light
Dynamic Range	Determined by Detector
Spectral Resolution	$\Delta\lambda$ = 0.02 Å
Polarization	Instrument Response to Polarized Light Should be Measured
Calibration	Ground Calibration Only
Observation Time	$\leq$ 5 Minutes (Time to Record Spectrum Varies with Instrument Design, Wavelength Range, Detector Choice)
Field of View	Determined by Limitations of Optical System; Spectra of Full Solar Disk Would be Obtained by Scanning Instrument

580 to 1220 Å Wavelength Range - Low signal strength due to low flux levels and poor mirror reflectivity remains a problem in this wavelength region. Suppression of stray light from the longer wavelengths and detector sensitivity are the principal design problems. Although photographic film is the traditional detector for this type of experiment, recent developments in electronic detectors should also be considered for this wavelength range.

Parameter	Requirement
Wavelength Range	580 to 1220 Å
Sensitivity	Optimize with Respect to Background Signal Level from Scattered Light
Dynamic Range	Determined by Detector
Spectral Resolution	$\Delta\lambda$ = 0.02 Å
Polarization	Instrument Response to Polarized Light Should be Measured
Calibration	Ground Calibration Only
Observation Time	$\leq$ 5 Minutes (Time to Record Spectrum Varies with Instrument Design, Wavelength Range, Detector Choice)
Field of View	Determined by Limitations of Optical System; Spectra of Full Solar Disk Would be Obtained by Scanning Instrument

1150 to 1800 Å Wavelength Range - The increasing solar flux levels and improved optical surface reflectivities considerably ease the problems of instrument design. More complex optical systems can be employed, increasing the amount of data collected per exposure. It would not be necessary to accommodate the entire wavelength range in one exposure; modifications of the instrument or the grating position between flights could be used to cover the entire wavelength range over several different missions.

The performance requirements are tabulated.

Parameter	Requirement
Wavelength Range	1150 to 1800 Å
Sensitivity	Determined by Detector
Dynamic Range	May be Varied with Mission Depending on Solar Lines to be Observed
Spectral Resolution	$\Delta\lambda = 0.02$ Å
Polarization	Instrument Response to Polarized Light Should be Measured
Calibration	Ground Calibration Only
Observation Time	$\leq$ 5 Minutes (Time to Scan Complete Spectrum Varies with Instrument Design, Wavelength Range, Detector Choice)
Field of View	Determined by Limitations of Optical System; Spectra of Full Solar Disk Would be Obtained by Scanning Instrument

3. Special-Purpose Measurements

The special-purpose measurements are divided into the five categories of instruments with rapid data rates and high sensitivity, instruments with high spectral resolution short time interval, instruments to provide a display of the cluster field of view, instruments that could be used in sub- or slave-satellites to ASF, and instruments that could perform *in-situ* measurements.

a. Rapid Data Takers - These are divided between the UV-Visible and the infrared.

Filter Photometers for UV and Visible - Some studies of atmospheric composition, structure, and dynamics require very high time resolution over known and fairly broad spectral regions. Filter photometers are appropriate for continuous, short-time constant monitoring of very faint or fast-changing scenes.

Performance requirements for such instruments are tabulated.

Parameter	Requirement
Wavelength Range	Discrete Bands Between 1050 and 8000 Å
Sensitivity	0.1 R (at SNR = 1 and Observation Times of 1 msec)
Spectral Resolution	15 Å Filter Passband
Observation Time	$\geq$ 1 msec
Field of View	Adjustable From 1 arc min to 1 deg
Radiometric Accuracy	±5% Relative
Off-Axis Light Rejection	10^6 (at 10 arc/min Outside of Nominal Field of View)

Infrared Radiometers - Consideration has been given to the inclusion of narrow band infrared radiometers. Spectrometers would have scan times of tens of seconds, and would not be able to observe transient phenomena in features such as aurorae ($\lesssim$ 1 sec). Furthermore, higher sensitivities would be possible with radiometers, and because of the probability of a single spectrometric instrument covering at least three spectral bands at separate times with component interchanges, the spectral coverage of the overall instrument complement could be strengthened by including an array of radiometers in those regions of the spectrum not covered by the spectrometers, e.g., radiometers operating in selected bands in the 15 to 150 μm region, along with a spectrometer configured to scan 5 to 15 μm.

Parameter	Requirement
Maximum Sensitivity	4×10^{-11} w cm^{-2} sr^{-1} μm^{-1}
Maximum Spectral Resolution	$\sim$ 1 μm
Radiometric Accuracy	$\leq$ 10%
Field of View	$\sim$ 3 arc min, and Wider
Filter Positions	Up to $\sim$ 8

b. *Dynamics--Fabry-Perot Interferometer* - Investigations of atmospheric structure and dynamics require very high spectral resolution in a fairly short time interval. The only instrument that appears to have the required large etendue and high resolution is a large aperture Fabry-Perot interferometer. The function of the Fabry-Perot would be to measure the shapes of spectral lines emitted by the upper atmosphere. The line width would show the effect of thermal Doppler broadening. Temperature of the emitting gases is the datum produced by the Fabry-Perot experiment.

Emission lines from ultraviolet to red are of interest, requiring instruments from about 2500 to 7000 Å. Contemporary Fabry-Perot plates attain the necessary high reflectivity with multilayer thin-film coatings. Such coatings, however, do not have uniformly high reflectivity over a wide spectral range, implying that more than one set of Fabry-Perot plates may be needed if measurements would be desired at widely separated wavelengths in a single mission. The spectral resolution required is about 10^{-2} Å.

A large etendue is required to achieve adequate signal-to-noise ratios for faint sources in the relative short observation time available for near-Earth orbit. This requirement implies that three parameters be kept as large as possible:

1) Finesse;
2) Transmittance;
3) Area.

A large finesse allows high resolution and large fields of view simultaneously. Large fields of view, of course, increase the etendue. The allowable field of view is limited by differential Doppler shift of the source relative to the observing platform, as well by the Fabry-Perot parameters. The transmittance of the Fabry-Perot includes the effects of an interference filter that blocks interferometer orders other than the one of interest. Large area directly increases the etendue but also leads to manufacturing difficulties that invariably reduce the possible finesse. Current technology allows a finesse of about 12 to 15, transmttance of about 0.45, and areas of 180 mm^2 The latter feature exhibits the best possibility for substantial improvement.

One preliminary requirement would be a signal-to-noise ratio of unity in 0.1 sec with a source radiance of 10 kR and resolution of 0.01 Å. The field of view would be determined by the etalon spacing, which in turn would depend on desired resolution and instrumental finesse. At this time other instrumental parameters are not well defined.

c. *Display of Field of View* - An on-line TV camera system would be included in the main instrument cluster. The purpose of this system would be to provide a visual display to the payload specialist of the scene observed by the instruments.

The on-line display system would consist of a zoom lens and a TV camera. The preliminary performance requirements are tabulated.

Parameter	Requirement
Wavelength Response	S-20
Field of View	2 to 20 deg (Continuous)
Angular Resolution	1 arc min
Signal/Noise Ratio	32 dB (at 3 ft-L)
Gray Scale	64 Levels, 6 Bits

A similar TV camera system would be required for the previewer mount. There the camera system would provide the payload specialist with a display of upcoming scenes, and allow him to search for transient features of interest. The performance requirements for this camera are similar to the on-line viewing system.

d. *Subsatellites* - With the extra payload carrying capacity of the Shuttle, it would be possible to carry one or more subsatellites that can be placed in orbits different from that of the instruments on the ASF. Tracking a simple satellite at low altitude could provide a measure of atmospheric density, and equipping the satellite with laser retroreflectors would facilitate making absorption measurements along a line of sight from the ASF to the subsatellite. A more highly instrumented subsatellite might carry a mass spectrometer away from the disturbed environment of the Shuttle to take measurements representative of the undisturbed atmosphere. Active sources could be carried by the subsatellite such as a tunable frequency laser for absorption spectroscopy or backscatter experiments, or a single wavelength source for determining vertical aerosol profiles by observing the scattering along a line of sight from the subsatellite to the ASF. If the subsatellite were placed in a highly elliptical orbit with an apogee of 22,500 km for example, a video system could image the entire auroral zone of one hemisphere at one time. In such an orbit, an array of energetic particle detectors and magnetometers would sample a different region of the magnetosphere than would similar detectors on the ASF. Ionospheric perturbation experiments with electron guns could also be carried out by remote satellites.

e. In-Situ Measurements - Eight categories of instruments are discussed here and very general requirements are presented.

Neutral Mass Spectrometer - A mass spectrometer for the measurement of neutral molecules must be able to distinguish between outgassed substances from the Shuttle vehicle and the residual atmospheric consituents. This requires a mass range from 1 to 110 AMU and the ability to maintain a mass resolution of 10% or less in the valley between the krypton 82 and 83 peaks. The dynamic range of the instrument should extend from 10^{-7} to 10^{-4} torr. A quadrupole RF instrument with in-flight calibration capability is an example.

Positive Ion Mass Spectrometer - To measure thermal positive ion composition and concentrations, a separate mass spectrometer would be required that can distinguish all important atmospheric constituents in the range 1 to 36 AMU. The instrument must be capable of operating over a range of ion densities from 0 to 2×10^6 ions/cm^3.

Ion Trap - A plane geometry ion trap working on the retarding potential analyzer principle would be capable of measuring ion composition and concentrations, and also ion temperature. By reversing voltage polarity, fluxes of suprathermal electrons could be measured and their temperature determined. Ion concentrations from 5 to 5×10^6 cm^{-3} and electron fluxes greater than 10^6 cm^{-2} sec^{-1} could be accommodated.

Electron Concentrations - A Langmuir probe could be extended into the plasma surrounding the Shuttle to measure the concentration of free electrons. By sweeping the voltage on the probe with respect to the vehicle potential the exponentially increasing current would allow the temperature of the electrons in the plasma to be determined. Densities from 10^2 to 5×10^6 electrons cm^{-3} should be accommodated.

Photoelectron and Energetic Particle Spectra - Measurement of the energy spectra and spatial distribution of photoelectrons and energetic particles in the ionosphere could be accomplished by a hemispherical electrostatic analyzer. By applying the proper voltage to inner and outer concentric hemispherical shells the intensity and energy distributions could be determined for photo-electrons from 2 to 100 eV, primary electrons from 50 to 30 KeV and energetic particles above 20 KeV. Directional information on the fluxes would be obtained by pointing the collection aperture of the instrument in different directions. An open wire mesh multiplier would serve as the electron detector while silicon solid-state detectors would be used for energetic particles from 20 KeV to 2 MeV.

Medium and High Energy Particle Detectors - In auroral zones it would be necessary to monitor the flux, energy spectrum, and arrival direction of the high-energy particles exciting the optical emissions and ionizing the atmosphere. A 10-deg pitch angle resolution would be desired for electrons and protons in an energy range of 1 to 1000 KeV. If the required spatial resolution of 100 is to be achieved, each detector must be sampled every 17 msec, which leads to a significant data handling problem.

Magnetic Field Measurements - Triaxial flux gate magnetometers with a sensor range of ± 60,000 gamma should be capable of making measurements with an accuracy of 0.1% up to a frequency of 5 Hz. To detect higher frequency magnetic field fluctuations up to a frequency of 10 kHz a set of triaxial pickup coils would be used. To place the magnetic sensors sufficiently far from the Shuttle so that the vehicle induced magnetic fields are negligible, booms extending out to 1000 m may have to be provided.

Electric Field Measurements - Three component electric dipole probes should be capable of measuring fields to an accuracy of 0.5 mv/m with a sensitivity of 0.1 mv/m on each axis. Variations in field strength from dc up to 10 kHz should be measured. Maximum dc fields are 200 mv/m with a 500 mv/m alternating component. Combined data from the electric field, magnetic field, and energetic particle detectors would provide important information on wave particle interactions in the magnetosphere.

B. POINTING AND CONTROL

The pointing and control requirements are discussed in terms of the three basic instrument clusters.

1. Main Instrument Cluster Pointing and Control

The purposes of the main instrument cluster pointing and control system would be to provide pointing and stability, to generate scan patterns and to record gimbal angles for data reduction. The need for an independent system is evidenced by the fact that the baseline capabilities of the Shuttle attitude control system do not meet the requirements for ASF. The Shuttle baseline capabilities are:

1) Absolute position, 700 ft;
2) Relative pointing, 0.2 deg;
3) Stability, ±0.5 deg.

The performance requirements for the ASF main instrument cluster are:

1) Absolute pointing- 3 arc min;
2) Relative pointing, 20 arc sec;
3) Stability, 2 arc sec.

In addition to pointing and stability it also would be impractical to hard mount the ASF to the payload bay and use the Shuttle to scan. The ASF performance requirements are:

1) Scan rates, up to 5 deg/sec;
2) Scan types: raster, horizontal, vertical;
3) Gimbal limits,

   a) Outer gimbal ±90 deg,
   b) Middle gimbal ±70 deg,
   c) Roll gimbal 360 deg.

The ASF requirements relate to the Shuttle baseline of June 27, 1972. Since then improvements on the Shuttle attitude control system have been proposed. If this is the case and the stability of Shuttle could be upgraded, then ASF may not have to provide its own stabilization. It could use the Shuttle as a base and eliminate the ASF stabilization system. ASF would still require its own gimbal system because it would be impractical to scan the instruments with the Shuttle.

2. Solar Monitor

The requirement for simultaneous solar observations has necessitate a separate solar monitor gimbal mount, which would automatically acquire and track the solar disk. Several of the instruments in the solar monitor have fields of view less than that of the solar disk. In order that the instruments may record the integrated energy of the entire disk, the gimbal mount must scan these instruments over the disk. Preliminary performance requirements for this mount are:

1) Relative pointing, 6 arc min;
2) Stability, 1 arc min;
3) Scan rate, 2 arc min/sec.

3. Previewer

A third independent mount is the previewer gimbal, which would point the TV camera and photometers, and would be controlled by the payload specialist using a steering lever. A further requirement on this system would be that the main instrument cluster must be able to be slaved automatically to the line of sight of the previewer, with a registration of 3 arc min. The preliminary performance requirements for the previewer gimbal mount are:

1) Absolute pointing, 20 arc min;
2) Relative pointing, 5 arc min;
3) Stability, 3 arc min.

V. SUPPORTING ANALYSES

In this chapter, analyses of a supporting nature to the main effort of the study are presented. The chapter is divided into four topics: configurations, calibration, alignment, and a typical mission profile.

A. CONFIGURATIONS

It has been stated earlier in the report that one of the results of performing the preliminary design of instruments, telescopes, and so on, is that it leads to the definition of overall configurations for the ASF. These ideas have been developed for the instrument clusters, as well as for the entire facility. The concepts are highly conjectural at this time, but reflect some of the possibilities for the facility as a Shuttle payload. It should be understood that the eventual configuration for the ASF will evolve through a number of intermediate steps. The heart of the facility is its instrument complement, and early versions will probably consist of nothing more than the telescopes and instruments mounted within the Shuttle payload bay, and remotely operated from inside the Shuttle vehicle. Later versions may include a habitable control module in the payload bay as well. The figures that follow represent a collection of all of the concepts that have been discussed during the objectives study, but do not imply a commitment to specific hardware.

1. Instrument Configurations

a. Main Instrument Cluster - Figure V-1 illustrates the main ASF cluster of instruments. The cruciform configuration was chosen to provide maximum mounting surface in a minimum volume. The four general-purpose instruments are present, as well as a bank of four photometers, documentation cameras, and TV display camera. All instruments are boresighted to a common field of view. Individual instruments may be accessed from the rear of the cluster enclosure, and would be guided to or from their respective attachment points by guide rails. The relatively loose arrangement facilities evolution of the instrument mix. One quadrant of the enclosure has been left empty, in recognition of the fact that the facility should be able to accommodate additional special-purpose instruments, or instruments designed and built elsewhere, provided that they would interface properly--the so-called "suitcase" experiment.

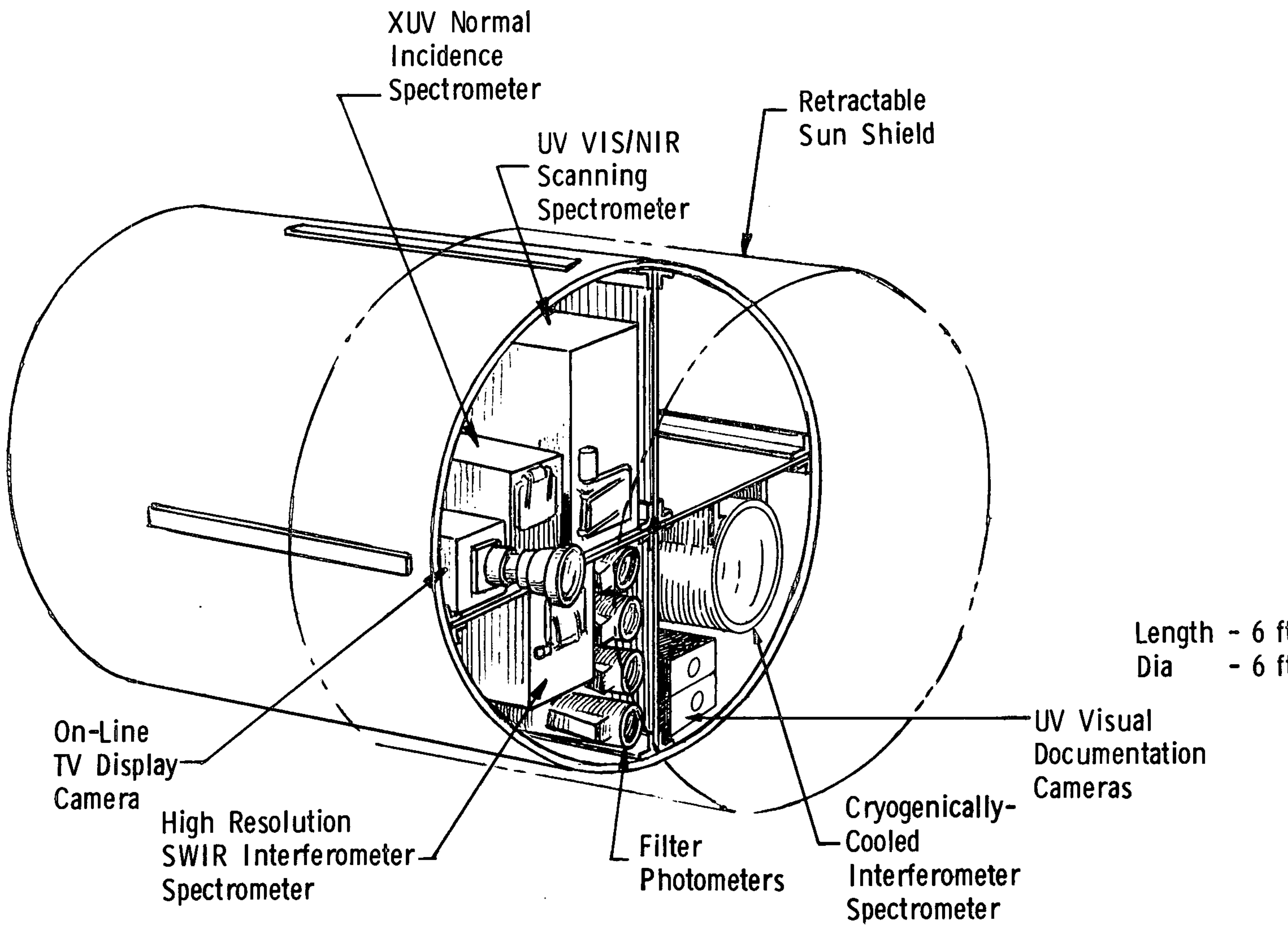

Fig. V-1 ASF Main Instrument Cluster

The cluster enclosure illustrated would be 72 in. in both diameter and length. Also pictured is a retractable sun shield that would extend approximately 3 ft beyond the forward end of the enclosure.

Figure V-2 presents a concept of the gimbal mount for the main cluster. Three gimbal axes would be provided, the innermost being a roll about the line of sight. The gimbaled star trackers discussed in Appendix A are shown. The main frame of the gimbal platform would be approximately 10 ft long, and the total assembly, including the main instrument cluster, would weigh from 1500 to 2000 lb.

b. Solar Monitor - The three XUV-UV solar line profile instruments and a concept of the XUV-UV solar intensity monitor package are illustrated in their gimbal mount in Fig. V-3. Ample space exists in this configuration to accept the necessary instrumentation for expanded solar measurements in the visible and infrared, which were suggested at the October 1972 meeting. The solar tracker is located at the forward end of the enclosure, and normally would provide automatic tracking signals directly to the gimbal torque motors. Manual override and slewing control would be available to the payload specialist at the control console. The instrument enclosure shown is about 50 in. in diameter and about 75 in. long. The entire assembly would weigh approximately 600 lb.

c. Previewer - Figure V-4 illustrates the previewer assembly in its gimbal mount. A TV display camera with a zoom lens is shown, along with two photometers, which monitor selected wavelength bands, and extend the previewing capability to spectral regions inaccessible to the TV cameras. A retractable sun shield would be provided for these instruments, as well. The instrument enclosure would be about 48 in. long and about 24 in. in diameter. The entire assembly, including the gimbal mount, would weigh approximately 200 lb.

d. Additional mounts - With the likelihood of additional instrument systems becoming part of the ASF complement, the possibility for other gimbal mounts arises. Active laser systems would probably require a separate mount to house their optical and electronic systems, which may differ significantly from the type required for the passive sensors. It may be desirable to isolate all instruments that are designed to take data very rapidly from the slower, scanning instruments, either on an independent mount, or perhaps on the mount containing the active systems. The wide variety of *in-situ* instruments may require not only mounts within the pay-

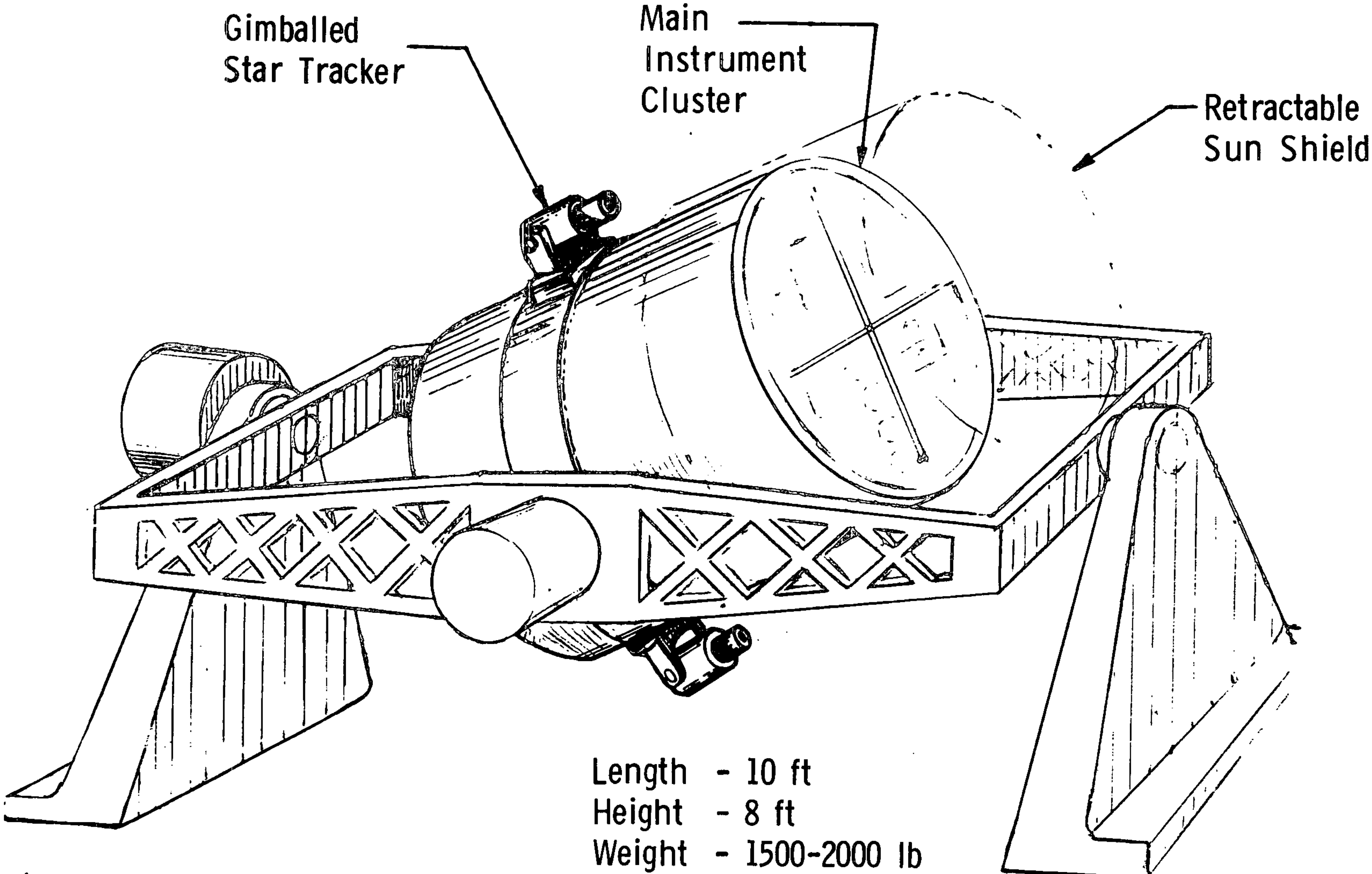

Fig. V-2 Main Instrument Cluster and Gimbal

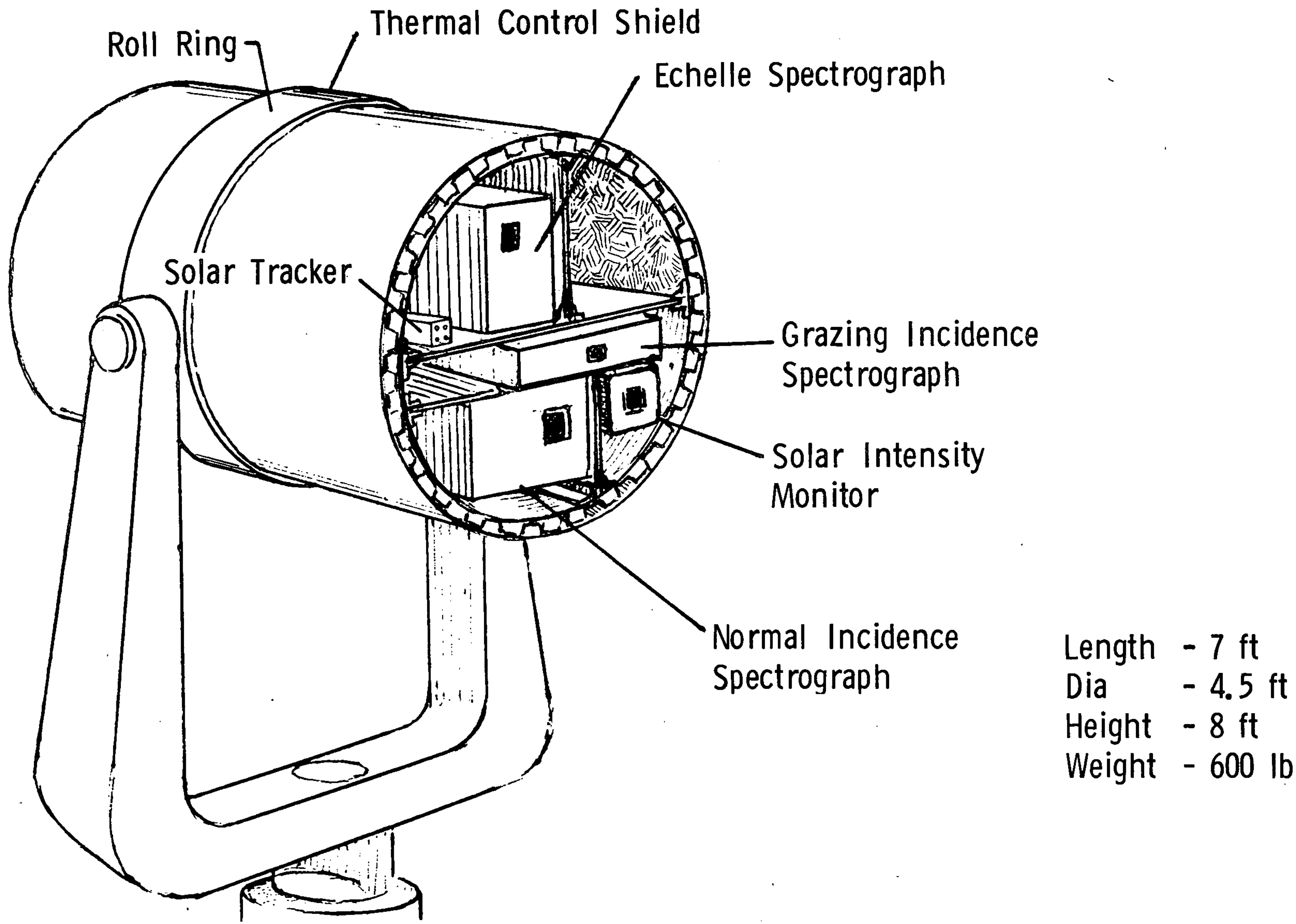

Fig. V-3 Solar Monitor and Gimbal Mount

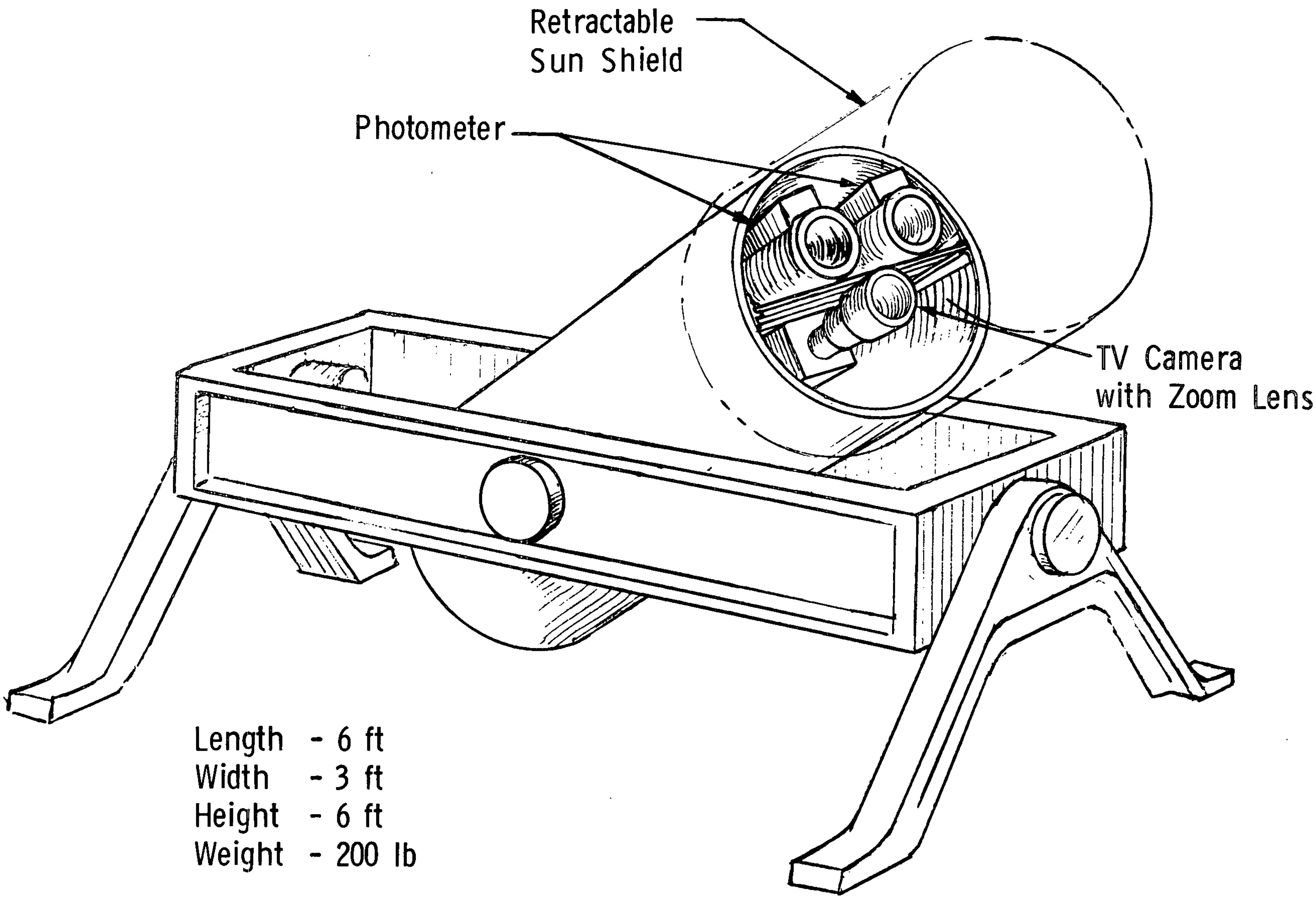

Fig. V-4 Previewer and Gimbal Mount

load bay, but also extendable booms or remote maneuvering devices for removing the instruments from the contaminating influences of the Shuttle Orbiter.

2. Overall Facility Configurations

a. Minimum Configuration for Early In-Orbit Development - A concept arising out of the Science Objectives Study for initial in-orbit development missions for ASF is illustrated in Fig. V-5. Three instrument clusters are depicted in the Orbiter bay, and would be fully exposed to the vacuum of space. A minimum of controls, display, and data handling capability would be available within the Orbiter cabin. Access to the instruments would be possible through an EVA operation only, and flexibility in the experiments possible on an extended mission would be distinctly limited. It is possible, however, that a configuration such as this could become available in sufficient time to participate in some of the early Shuttle development and checkout missions in 1978.

b. Development Configuration with Enclosed Module - Another early concept for the ASF configuration is presented in Fig. V-6. In this configuration would be a chamber that may be evacuated and in which the collecting optics and instruments of the main cluster are located. This chamber would have a roll back observation port permitting the entire instrument cluster to be operated in vacuum. Included would be tanks for cryogens or additional atmosphere to be used for repressurization of the chamber should it become necessary to enter the chamber to replace malfunctioning instruments or components, or to change the experiment mix during a given mission per plan, or to change the mix on the basis of an altered mission plan. The other two instrument packages would remain in vacuum, and controls, displays, and data handling functions would continue to be performed from within the Orbiter cabin.

c. Integration with Sortie Laboratory - A further configuration is shown in Fig. V-7. This concept envisions a highly autonomous payload in which all viewing, status monitoring, processing, operation, and control are performed from within the payload facility. This basic payload would consist of a sortie laboratory and ASF module, connected by an airlock. This concept offers all of the access flexibility of the enclosed module concept, plus the increased versatility of more onboard data processing and display--allowing more on-the-spot decisions by the scientist payload specialist. Also recognized in this concept is the possibility for ASF subsatellites, either released into a similar orbit as the Shuttle, or containing kickstages to carry them into special orbits of high altitude or ellipticity; secondary atmospheric science payloads, not directly connected with ASF operations; or Shuttle standard service units, for servicing unmanned satellites already in orbit.

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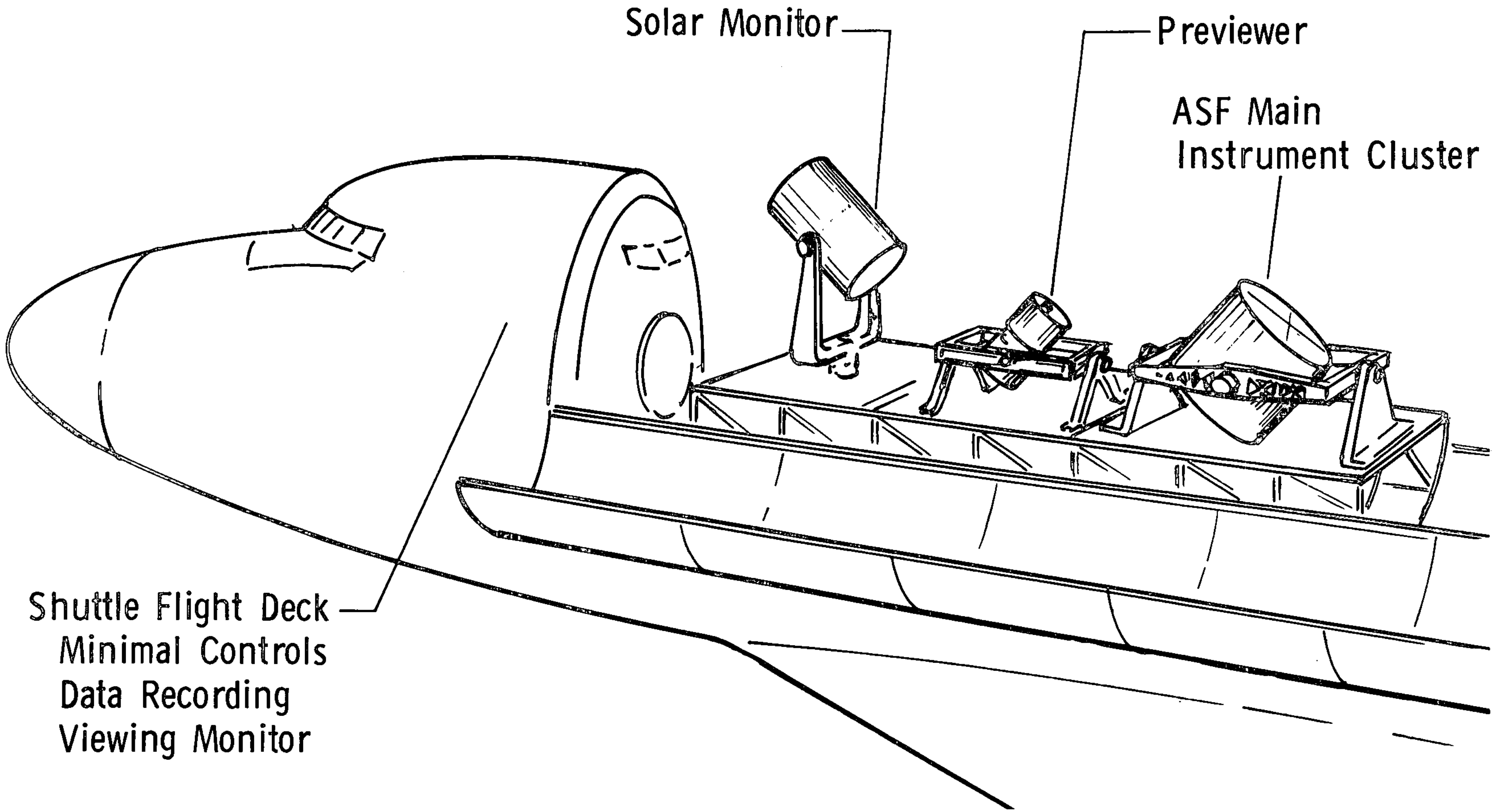


Fig. V-5 Minimum Configuration for Early in-Orbit Development

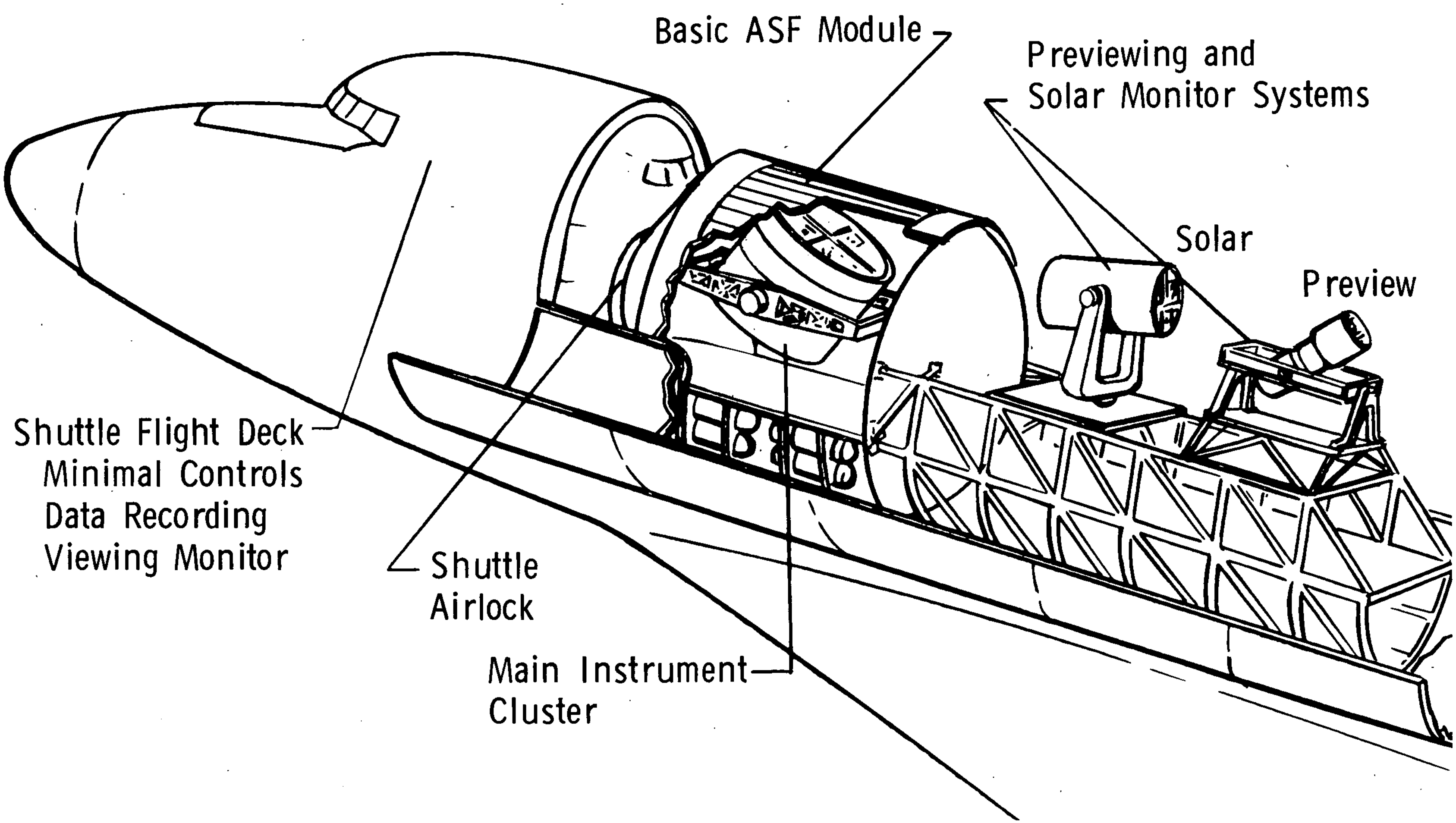


Fig. V-6 Development Configuration with Enclosed Module

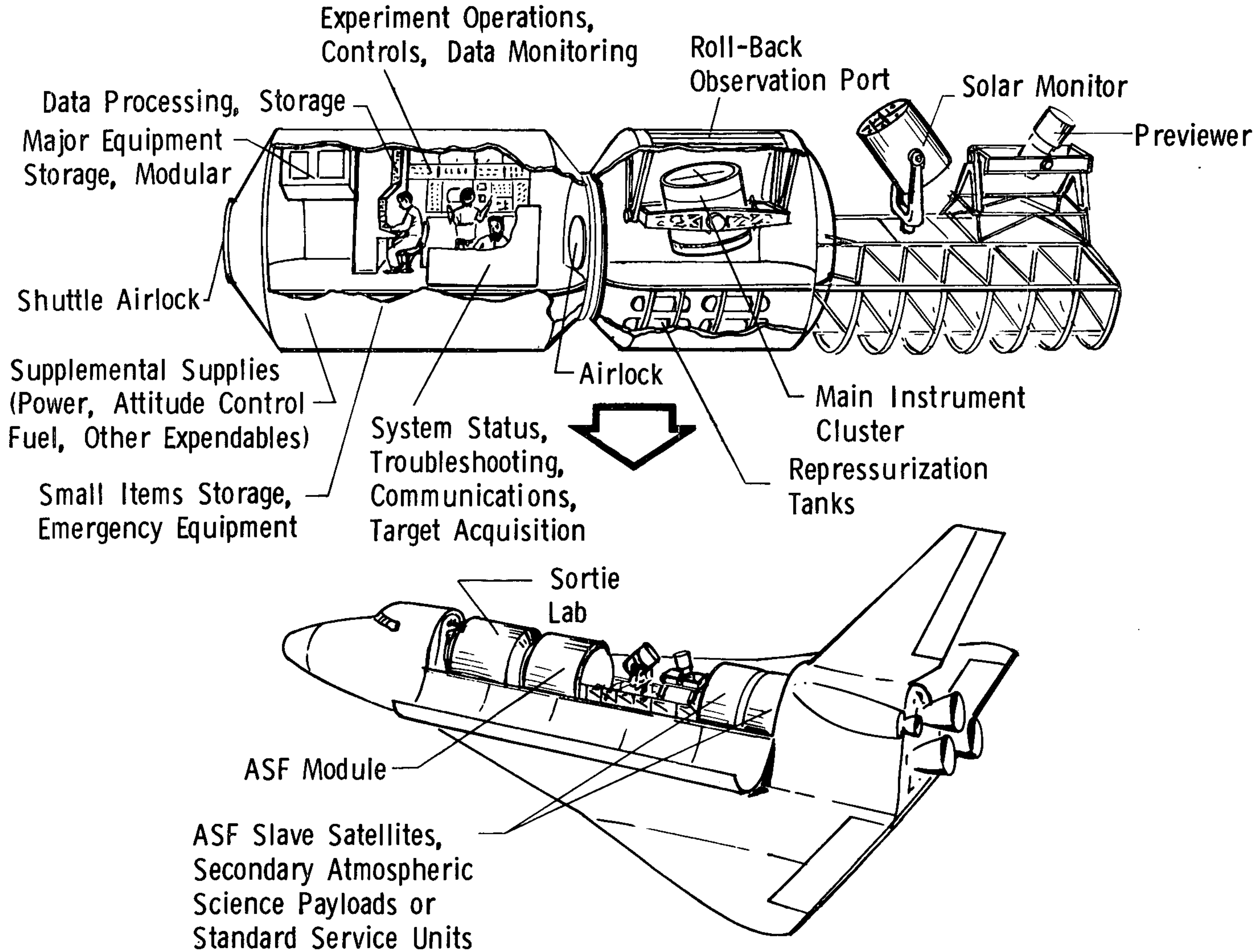


Fig. V-7 ASF/Sortie Lab Integration

B. CALIBRATION

The presence of man with the instrumentation and the ability to return the payload to Earth makes possible significantly more accurate observations with Shuttle payloads than are currently made with unmanned space instruments. The ASF calibration philosophy is that the instruments would be removed from the mounting pallet and calibrated on the ground before and after flight. In addition, the ability of the Shuttle to carry calibration sources of large weight and volume enables calibrations to be made in orbit to ensure the highest radiometric accuracy, and to check for degradation caused by contamination or other effects of the exposure to the space environment.

The instruments would probably not be removed from their mounts for orbital calibration, but would be swiveled to point into arrays of sources large enough to fill the instrument apertures. Blackbodies at both cryogenic and ambient temperatures would be used to calibrate the infrared radiometers and interferometers. Standard lamps or, possibly, a synchrotron source would be used to calibrate photometers and spectrometers in the visible and ultraviolet. Because open window discharge lamps are difficult to operate in an unattended environment the sun could be used as a source to feed a premonochrometer that would calibrate the solar intensity monitor. Observation of the moon and of stars with known spectral distribution could also be used to verify calibration in orbit.

C. ALIGNMENT

Because of the gentle launch environment provided by the Shuttle, no problems are anticipated in instruments losing alignment during launch or reentry. Therefore, no operations are planned in which the crew would alter the alignment of the instruments in orbit, unless it was necessary to replace a component. If this should occur, the instrument design must include special provisions to permit the alignment of the replaced component, because in general this is a nontrivial and time consuming operation. The general internal alignment of a spectrometer or other sophisticated optical instrument is not a suitable job to undertake in orbit on a short-duration mission such as ASF. Alignment of a cluster of instruments to the pointing system, however, should be checked in orbit by observing a point source such as a star. If a misalignment has occurred, either the system would be realigned on the ground after the mission is over, or provisions may exist for adjusting the fine pointing of instruments within the cluster.

D. TYPICAL MISSION PROFILE

In this section, a typical mission profile will be illustrated. The emphasis will be on the experiments rather than on the personnel or Shuttle timelines. These timelines will not be ignored, but the focus will be on the ASF objectives and the timelines will be used as boundary conditions. The experiments will be discussed with respect to the following time scales:

1) Entire mission (7 days);

2) One day (∿16 orbits);

3) One orbit (∿90 minutes).

The mission will assume the following orbital characteristics:

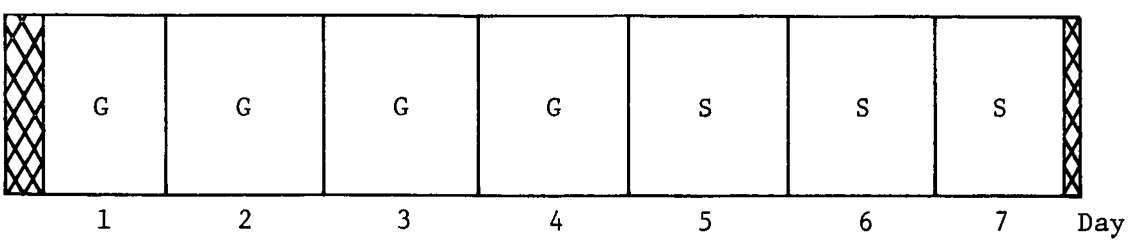
1) Altitude, ∿250 n mi;

2) Inclination, polar;

3) Eccentricity, low.

1. <u>Seven-Day Mission</u>

For the typical seven-day mission, the time may be divided into seven 24-hr periods as shown below.



In the sketch above, the two hatched areas represent Shuttle maneuvers and get-ready times as delineated in Table V-1. The areas marked G are general-purpose devoted periods, at which time experiments of a general nature would be undertaken. Experiments in this class are low spectral and spatial resolution mappings of the atmosphere. The areas marked S are special-purpose periods where planned experiments of a special nature would be performed. Note (Table V-1) that about 160 hr of observation time are available for a seven-day total mission.

<u>One-Day (16 Orbits)</u>

In a typical day on Shuttle, the time lines of the crew impact the observing schedule as is shown in Fig. V-8. The following guidelines have been observed:

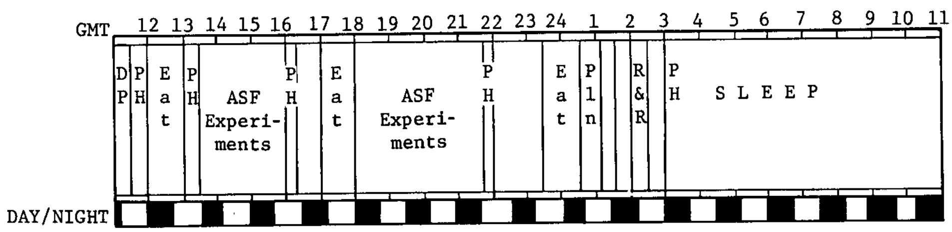
1) All crewmen are scheduled for 8 hr sleep/day;

2) The crew duty day is between 6 a.m. and 10 p.m. CST;

3) Each crewman is scheduled 1.5 hr/day for personal hygiene;

4) 1 hr meal periods, at 7 a.m., 12 noon, and 6 p.m.;

5) Each crewman is allowed 30 min/day for exercise.



Legend:

PH - Physical Hygiene

DP - Daily Preparation

Check Teleprinter for Updates

Configure Systems

Check Experiment Status

R&R - Rest Recreation

Pln - Planning

Fig. V-8 Typical Crew Day

Table V-1 Typical Timeline for a Shuttle/ASF Sortie Mission

Elapsed Time	Event
00:00	Liftoff
00:06.5	Insert into 50x100-n-mi Orbit
00:50.1	Transfer to 100x250-n-mi Orbit at First Apogee
01:35.8	Circularize at 250-n-mi Orbit at First Apogee, Check Out Orbiter Systems, Update Ephemeris, Open Orbiter Payload Bay Doors, Verify Readiness to Proceed with Experiment Operations
02:00	Orbiter Course Attitude Acquisition
02:30	Turn on the Electrical and Thermal Control Systems
02:35	Turn on Control and Display Panel
02:45	Instrument Checkout and Calibration
04:30	Conduct Experiments
.	.
.	.
.	.
164:00	Secure Instruments
165:48	Turn off Control and Display Panel
165:52	Turn off Electrical System
165:54	Check Out Orbiter, Prepare for Return to Earth
166:54	Initiate Deorbit

In Fig. V-8, the observation periods are 1300-1700 GMT and 1800-2300 GMT, a total of 9 hr/day. Also shown are the day/night conditions of a typical orbit.

3. Single Orbit

In this section, a typical orbit will be examined in both a general- and a special-purpose mode.

a. One Orbit (General Purpose) - The orbit to be considered will be a polar orbit and the following regions of the Earth and their observation times will be covered;

1) Northern polar region, 20 min;

2) Between the poles (day side), 25 min;

3) Southern polar region, 20 min;

4) Between the poles (night side), 25 min.

The instruments used for the general-purpose observations are:

1) General-purpose spectrometers;

2) On-line TV camera;

3) Documentation camera;

4) Previewing TV camera;

5) Photometers.

These instruments used in the polar regions of the orbit would monitor auroral emissions with low spectral and spatial resolution. The entire polar region would be mapped. As the Shuttle continues its orbit (between the poles, day side), the general-purpose instruments would continue to map the atmosphere, monitoring airglow emissions. In coincidence with the airglow mapping, the XUV-UV solar intensity monitor could be used on the solar radiation. The observations on the southern polar region would be identical to those in the northern polar region. On the night side of the orbit the instruments would continue to make this general survey. Concurrently, the crew would search for areas of interest that might be used to direct the observations during the special-purpose portion of the mission.

b. One Orbit (Special-Purpose) - In a special-purpose orbit, the regions of the atmosphere to be investigated would be identical to those covered in the general-purpose observations. The difference is that specific emissions would be monitored. While over the poles, emissions that showed significant activity would be monitored. A search would be made for noctilucent clouds using the previewer. Measurements using the general-purpose instruments would be of high resolution, spectrally and spatially about areas of activity. As the Shuttle passes over the north pole the opportunity to do solar occultation measurements could arise. This experiment could be performed using the XUV-UV solar line profile instruments, which could also be used in conjunction with the upper atmospheric experiments.

Instruments used for the special-purpose orbit would be the general-purpose instruments, fixed at specific wavelengths. As an example, the tropical oxygen lines at 900 to 910° could be monitored on either side of the geomagnetic equator, using the XUV spectrometer. The UV-Vis/NIR spectrometer could also record data at the 1304 and 1356A lines of oxygen.

On the night side of the orbit, in addition to the high-resolution measurements being performed, stellar occultations could be made using the photometers and the radiometers.

Instrument calibration would be performed on at least two orbits per day, and preferably, the first and last observation orbit.

VI. RELATED STUDIES

Several topics related to this study are discussed in this chapter. They include discussion on the data management system for the Atmospheric Science Facility (ASF); the participation of man in its operation; new developments of interest in the areas of detectors and calibration; and, finally, a brief discussion of future activities in the ASF program.

A. DATA MANAGEMENT

The data management system concepts for ASF have been developed based on the operational and design requirements levied by the instruments. The data management system's support functions include:

1) Processing (for real-time display) of both scientific and engineering data;

2) Storage of scientific and engineering data;

3) Real-time command, control, sequencing, and video monitoring;

4) Receipt, storage, and distribution of command data from the ground;

5) Generation and distribution of onboard timing.

Because ASF is a proposed Shuttle payload, the data management boundary between Shuttle and ASF is a key overall consideration. The Shuttle data interfaces are:

1) Orbiter computer (10K, 32 bit words);

2) Wideband data link to ground (256 kbs);

3) Digital data transfer to ground (25kbs);

4) Two coaxial links for TV transmission, payload to Orbiter;

5) In-flight data uplink (2 kbs);

6) Two-way voice, payload to Orbiter;

7) Two-way voice, payload to ground.

During this study, the characteristics that evolved for an ASF payload data management system are:

1) Primary data format, digital;

2) Onboard storage;

3) Autonomous operations;

4) Higher-order language;

5) Preprocessing and display;

6) Telemetry to ground for large processing jobs and/or ground-based scientist involvement;

7) Uplink of results to ASF crew.

1. <u>Key Considerations in Data Management System</u>

The following items identify key considerations in defining the overall ASF data management system.

1) Experiment characteristics - What are the experimenter's needs rather than wants? Generally data volumes and NRT (near-real-time) readout requirements tend to escalate when bandwidths are considered. What data features are desirable or necessary and are the necessary algorithms available? Both are important questions.

2) Involvement of man increases needs for onboard preprocessing,

   a) Better displays need preprocessing/feature extraction,

   b) In-flight options and exploratory measurements tend to increase,

   c) Data collection tends to be more ambitious.

3) Decision tree for data processing tradeoff,

   a) Isolate areas that are firm constraints (Shuttle interfaces, ground link capacity, power, and weight),

   b) Define experiment mixes expected, mission profiles,

   c) Estimate (display and feature extraction) processing requirements to enhance man's role,

   d) Tradeoff Shuttle/payload and onboard/ground processing loads and cost effectiveness.

4) Clean Shuttle interface - The data interchange between the payload and the Shuttle should involve as few physical connections as possible.

5) Isolated integration - The data management system should be as highly integrated as possible and isolated from the Shuttle system to the maximum extent possible.

6) Standardization - Many of the payload support functions are similar from one payload to another. Support systems should be standardized along lines of commonality where feasible.

7) State-of-the-Art (SOA) Technology - Experiment support requirements must be compatible with SOA hardware and software. Available elements should be matched to the requirements where possible thus minimizing development costs.

8) Compatibility - Hardware and software elements should be configured to allow operational compatibility checks before Orbiter installation. This provision will assure validation of new elements without pad delays.

2. Ground Data Acquisition and Handling Assessment

The system design must determine requirements for acquisition, processing, and dissemination of experiment data and must assess the impact on existing MSFN, NASA Communication System (NASCOM), Ground Data Handling System (GDHS), and processing center capabilities.

Design work should analyze experiment objectives and encoding formats to identify data handling and processing functions requiring unique software and hardware. Areas where flags should be inserted in the data stream to facilitate computer processing must be identified. This work should include the following items:

1) Analyze up-link/down-link characteristics and prepare data loading estimates to evaluate capability of existing and planned hardware to satisfy the requirements. Prepare estimate of data types and quantity to be retained in archival storage.

2) Evaluate existing and projected NASA data networks and processing facilities as candidates for satisfying the experiment data requirements. Assess the projected equipment/program use as it impacts the experiment data system.

3) Evaluate other satellite programs (e.g., Skylab and ERTS) ground control functions and displays to identify techniques employed to satisfy similar experiment requirements. Identify requirements for unique displays requiring off-line processing.

4) Analyze requirements for acquisition, processing, and control of truth-site correlation data and determine projected capabilities based on Earth Resources Program, Skylab, ERTS, etc.

5) Develop data flow and identify functional interfaces necessary to define requirements for telemetry, command, communications, and tracking data.

3. Impacts of Software Languages

Shuttle and ASF software requirements are special in several ways. For example, the hardware configuration is distributed, flight support operations must be autonomous, fault tolerance is required, and changes must be accommodated throughout ASF/Shuttle useful life. Conventional aerospace software has generally implemented highly refined machine language coding on a single processor with limited memory and tight timing constraints. An example of machine level source language code is: "02000421 CLA VAR"; programming at this level is extremely costly to change, and virtually impossible for nonspecialists to implement.

The merits of High Order Language (HOL) programming are recognized for large complex systems, including both application and system programs. HOL advantages include readability, powerful operations, capability for detail, reduced program development time, and ease of changes. Disadvantages include the generation of possibly (not necessarily) inefficient code, and the fact that the detailed instruction sequence is hidden. An example of HOL level source language is: "023 Sum (Index) = Ref (Index) + A (Index) * B (Index)." HOL source listings are compact and relatively easy to change.

Many examples of specialized HOL exist. These languages are widely employed in test and checkout, query and command applications, report generation, and engineering design applications. An example of a specialized HOL statement might be: "Apply 24V to GIMBAL RELEASE SOLENOID". These languages attempt to make programming easy for technicians who are not programmers.

4. Data Flow

Figure VI-1 illustrates the possible data flow for the example ASF minimum/development configuration illustrated in Fig. V-5. The heavy broken line shows the interface between the ASF instrument package and the Orbiter.

If, on the other hand, the ASF/Sortie Lab (Fig. V-7) concept is considered, the interface between the ASF payload and the Orbiter is shown in Fig. VI-2. The design of an ASF data management system should be such that it would be flexible, and not overly restricted in capacity. What is envisioned is a system that could grow easily with the complexity and capacity of the Atmospheric Science Facility through the '80s.

B. MANNED PARTICIPATION

A preliminary analysis was conducted to provide future program guidance on the extent of astronaut participation in support of ASF experiments. The data developed from this analysis are based on the general conclusion that man is capable of performing the same tasks in space as he does on Earth provided that proper and adequate hand and foot restraints are used. Because planned ASF mission durations are less than those of recent Apollo and Soviet space missions, such a general conclusion can be viewed with some confidence. The manned space flight data collected to date have indicated no degradation in human cognitive, perceptual or motor capabilities in zero gravity. The only exception to this general conclusion involves some degradation of perceptual and motor capabilities during extravehicular activity, and all tasks in which an astronaut is encumbered in a pressure suit and associated life-support equipment.

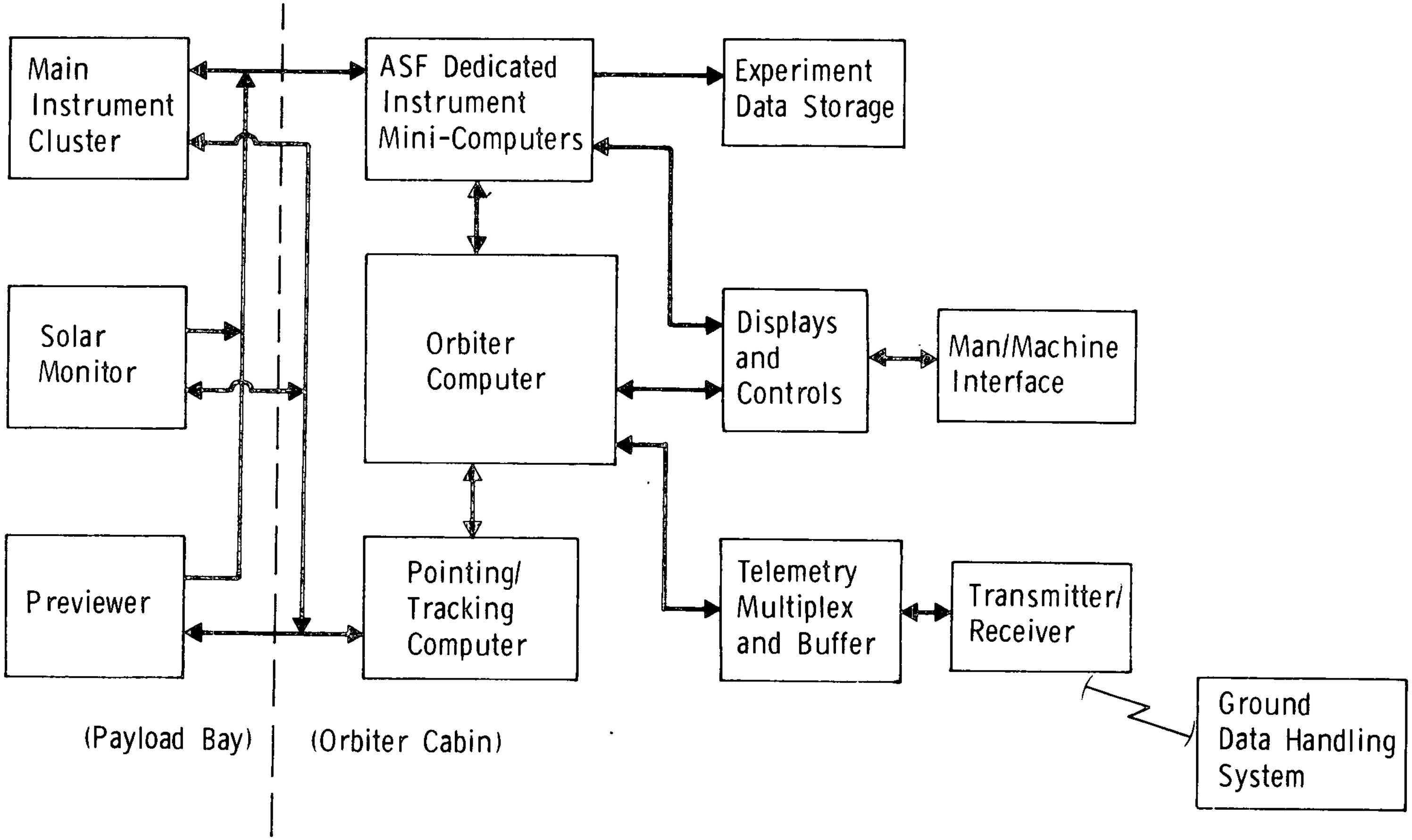


Fig. VI-1 ASF Data Flow Chart, Minimum/Development Configurations

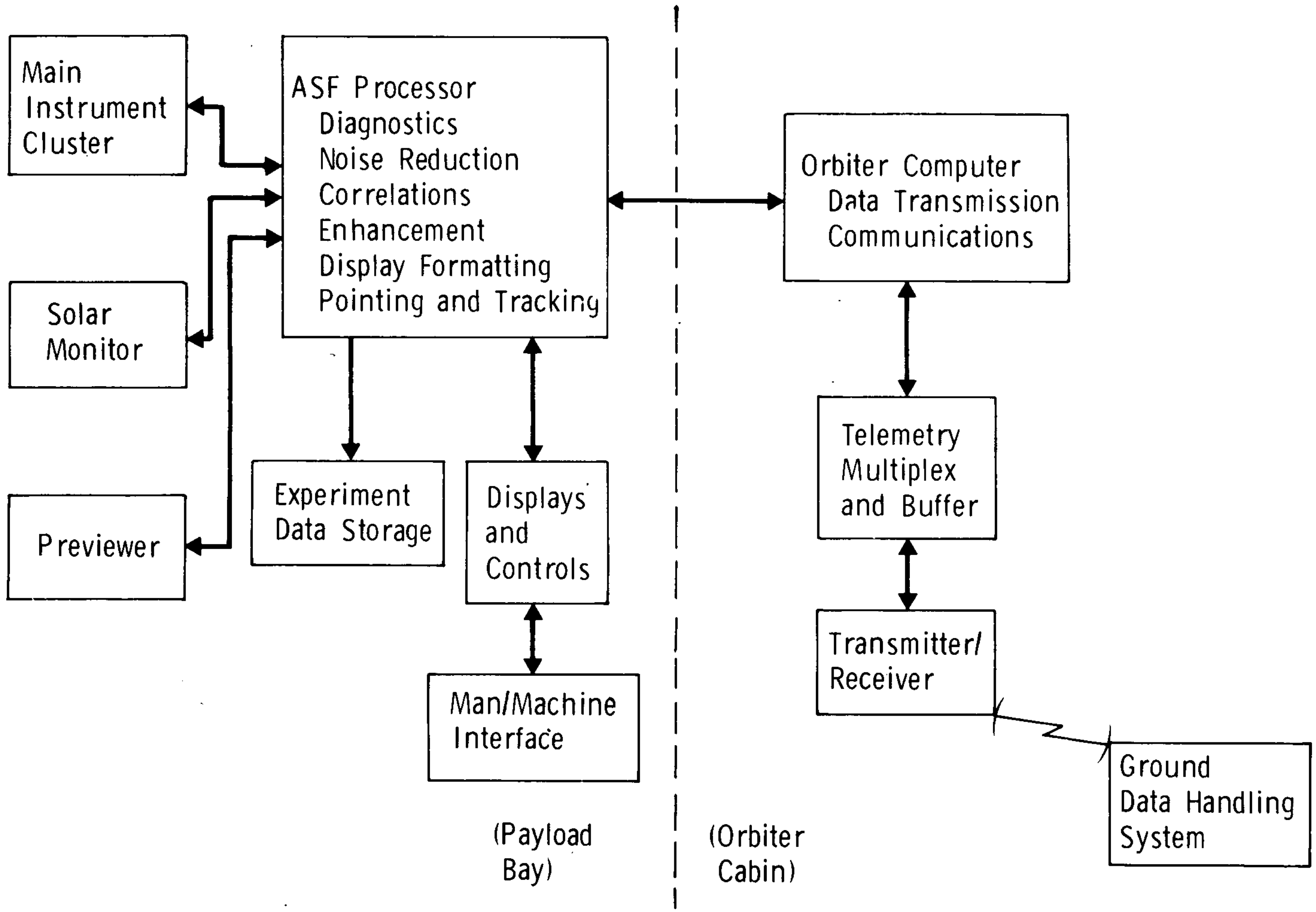


Fig. VI-2 Data Flow Chart, ASF/Sortie Lab Integration

1. Man-Machine Functional Allocation Considerations

Some functions are better allocated to man and some better allocated to a machine, whether the function is performed in space or on Earth. For example, man is poorly suited for functions like high-speed data computation or the generation of large forces. On the other hand, only man can perform certain functions like the discrimination of objects in unfamiliar surroundings or in extremely high noise fields. Most functions, however, can be performed by man or they can be automated, though not necessarily with equal effectiveness. The ultimate decision to allocate any specific ASF function to man or machine requires the consideration of many system variables that are unspecified at this time. However, certain data pertinent to the problem of man-machine allocations have been assembled and are presented in Tables VI-1 and VI-2. Table VI-1 lists man-machine tradeoffs for general ASF experiment and operational functions. Table VI-2 presents a listing of potential crew contributions to ASF experiments as currently conceived.

2. ASF Personnel and Skill Requirements

If man is to participate in ASF experiments, then full advantage should be taken of his talents and capabilities. Based on the data presented in Tables VI-1 and VI-2, and on an assumed requirement for a three-man ASF crew, probable personnel and skill requirements have been developed. The types of personnel, the typical activities each would perform, and their associated skill levels are shown in Table VI-3. The working assumption of a three-man ASF crew has been reinforced by the results of these tables and by subsequent sections of this analysis. Based on the apparent requirements for operation of the ASF, both in activities and in skill levels, and on the anticipated degree of instrumental complexity, it has been concluded that a three-man ASF crew is optimum.

3. Utilization of Man

The ASF crew would initiate, monitor, assess, verify, and terminate the tasks of checkout, setup, deployment, alignment, calibration, indexing, slewing, retracting, and stowing of the instruments and clusters.

The crew would assure that the correct targets are observed and that data quality is acceptable. The crewmen would decide (with, perhaps, voice consultation with ground-based scientists) when it

Table VI-1 Man-Machine Tradoffs in Atmospheric Science Facility Experiments

General Function	Specific Function	Can Function be Automated?	Value of Man
Deployment	1. Assemble delicate components.	Yes (in some cases)	1. Complex instruments, less chance of damage.
	2. Remove protective devices such as covers, lens caps, etc.	Yes	2. Simpler system for removing protective devices.
Alignment	1. Adjust orientation on different axes and compare effect of adjustment on data acquisition.	Unlikely	Time to align is 1/40 of that required by ground controlled alignment.
Spectral-Photometric Calibration	1. Take readings of known targets. 2. Choose integration times on basis of these readings.	No	Short time to calibrate compared to ground controlled calibration.
Operation	1. Check that equipment is operating within desired limits.	Yes	1. Increase in quality and amount of data.
	2. Change preplanned experiments.	No.	2. Provides flexibility in experiment.
	3. Change and process film/data tapes.	Yes	3. More useful data can be collected per mission.
Data Management	1. Culling data and deciding what should be transmitted.	No.	1. Increase in amount of useful data available in a timely fashion.
Maintenance and Repair	1. Maintenance Checks.	Yes (Partly)	1. Reduces probability of system failure.
	2. Replace failed modules	Yes (Partly)	2. Increases system reliability.
Retrofit	1. Replace functioning elements with newly developed state-of-the-art elements.	No	1. Optimize system performance and experiment flexibility.
	2. Replace functional elements due to change in experimental plan.	Yes (Partly)	2. Maximize type of data collected and provide experiment flexibility.

Table VI-2 ASF Crew Functions

Task Functions	Typical Activities	Crew Capabilities
Maintenance/Repair/ Resupply	Detect sensor and subsystem malfunctions Diagnose and correct malfunctions Service equipment Load cameras and recorders	Diagnostic abilities
Planner/Decision Maker	Make real-time mission decisions Assess critical operations Control mission operations and sequences	Reasoning abilities Ability to make decisions with incomplete information
Evaluator of Equipment, Techniques and Procedures	Real-time evaluation of equipment, techniques and procedures. Identify problems and potential solutions during early flight operations.	
Set Up/Checkout	Erect and deploy equipment Install equipment Calibrate and checkout of sensors and other devices	Manual dexterity Training Mobility
Retrieve/Store	Retrieval of film, instrument components Stow film and tapes	Ability to go EVA, if necessary Mobility
Communication/ Data Transmission	Report experiment progress, flight operations and observations of interest. Set up data transmissions to ground. Monitor transmission of data to ground.	Ability to interpret and verbalize information. Ability to plan ahead.
Public Relations	Inform public of program achievements	Ability to interpret concepts and events and present to public.

Table VI-3 ASF Personnel Requirements

Personnel Types	Typical Activities	Skill Levels
Scientist Investigator	Evaluate target selection Evaluate and assess data Evaluate target scene React to unanticipated events Evaluate sensor signals Perform inflight modifications Adjust sensor settings Change filters Search for targets of opportunity Acquire targets point and track Make real-time experiment decisions	Capable of operating all experiments in his field and familiar with the type of data required from each. Capable of preliminary data analysis for his own experiment(s) and other experiments with inputs from other ground-based PI's. Knowledgeable in all aspects of his experiment, hardware, operation and data analysis. Can re-program his own experiment operation (retake data) and other experiments with minimal inputs from ground-based PI's. Extensive training in pointing and tracking, image motion compensation, etc.
Information Manager/ Data Analyst/Data Editor	Voice annotation of tapes Monitor and edit data Manage tape recorders Data transmission	Can monitor experiment operation, and perform a limited amount of interpretation when aided by a scientist. Can re-program experiment operation per direction of scientist. Broad area of scientific knowledge. Capable of detailed data analysis.
Manager of Sensors and Subsystems	Monitor status of equipment Control sensors and subsystems Detect sensor and subsystem malfunctions Diagnose and correct malfunctions	Hardware oriented Can operate, trouble shoot, and maintain hardware according to established procedures and with supervision. Complete knowledge of experiment operation and ability to perform a limited amount of data taking/monitoring with supervision.

is necessary to retake data and when additional data are required. They would monitor the progress of each observation and terminate it should any unusual perturbation occur (e.g., outside of Shuttle vibration specification).

Of great importance would be the crew's ability to react to targets of opportunity, such as aurorae, violent storms, or noctilucent clouds. The ASF crew would coordinate with the Shuttle pilot to ensure that momentum dumps and waste ventings would not interfere with the scientific program. The crew would also coordinate with Earth stations to make changes in the observing schedule or to interpret unexpected data.

Table VI-3 lists in detail the typical activities and skill levels for the ASF crew.

4. Manned Participation in Typical Experiments

a. *Noctilucent Clouds* - The primary role for man would be to scan the twilight horizon and identify noctilucent clouds. This could be done visually or with the aid of simple filters to determine whether a luminous layer is emitting or scattering. The observer would tape verbal descriptions of the features and record these by simple photography.

b. *Stellar Occultation* - The observer would acquire the star with the on-line display system. On guiding the star within the reticle on the display he may then initiate automatic tracking and the actual occultation measurement.

c. *Pollution* - Sensors slaved to the previewing TV display system would give the observer the opportunity to track and study targets of great interest (e.g., cities, rivers, airports, etc). The observer could also be in frequent communication with the ground, particularly preceding and following pollution events.

d. *Aurorae* - The observer would visually observe the polar regions, as well as monitor the outputs of his previewer photometers. Upon sighting an area of auroral activity, he could then turn his other instruments on the scene, and using his steering lever scan the appropriate area. He would also initiate the documentation cameras.

e. *Meteorology (Weather Fronts)* - The observer would scan the atmosphere with the previewer for areas of high activity. This would be coordinated with ground observation stations. He would then turn the main instrument cluster toward the weather front and use his steering lever to point the instruments along the weather front boundary, while taping verbal descriptions of the gross features of morphology and brightness and recording these by photography.

f. Earth Observations - In performing Earth observations, the observer could prove to be indespensible. Here he would use the previewer to look for areas without cloud cover at which he would point the main instrument cluster. He could also coordinate his activities with ground truth sites and observe preselected areas that would use known sources of radiation directed at ASF. Again, the observer would annotate the tapes and take photographs.

g. Atmospheric Structure (Vertical Horizon Profiles) - The observer would scan the horizon with the previewer and then slave the main instrument cluster to the previewer line of sight. The instruments of the main cluster would then record data with a programmed scan pattern. The observer would monitor the outputs of the various instruments for the proper signal to noise ratio. With sufficient S/N, he would then direct the main instrument cluster to another portion of the horizon.

C. NEW DEVELOPMENTS OF INTEREST

During this study, several interesting new developments have been identified that have possible application to ASF. This section discusses two such areas, namely, recent developments in detection systems in all spectral regions, and the possible use of the synchrotron as an in-flight calibration source for all wavelength regions.

1. Detection Systems

Five recent developments that are of interest to ASF are discussed.

a. XUV Video Detector - A recent detector development in the XUV has been the coupling of a channel electron multiplier plate to a video detector. A phosphor on the back of the channel electron multiplier converts the electron cascade into a spot of visible light that is coupled to the vidicon faceplate by a fibre optics bundle. The spatial resolution is limited by the spacing of the individual channel plate elements, by the degree of alignment between the channel plate elements, the fibres in the fibre optics bundle, and the scan lines in the video raster. By operating the channel electron plate in a saturated mode, the detector can work as a digital counting device with the spatial registration of the incoming photons preserved. By using an integrating tube such as the SEC vidicon, the signal can be accumulated for an interval determined by the dynamic range of the tube and the strength of the brightest spot in the image. The tube is then digitally read out into a computer or storage device, and a new frame of data is accumulated.

Devices of this type have recently been assembled, and are being tested. It is a promising detector for the XUV airglow spectometer and for the solar line profile instruments.

b. Channel Electron Multiplier Linear Detector - Another XUV detector under current development achieves spatial resolution along one axis by placing a set of linear strip anodes behind the plate, with the width of each anode approximately equal to the separation between individual channel elements. Each anode strip is connected to a separate amplifier and collects the pulses from the multiplier plate along the length of the anode strip. The device is promising for use in the solar line profile instruments.

c. Video Detector Data Systems - While the manipulation of digitally recorded data from a video detector is an established technology, the software required to implement a particular requirement can represent a significant cost item and consume a considerable amount of time before a data processing routine is debugged. The development of hardware systems and software processing routines to process this type of data is being accomplished by several manufacturers. By using a commercially available system instead of one requiring individual design, significant program economy would be effected. Some of these systems are specifically designed to process and display spectral data, which is the most promising ASF application.

d. Ultraviolet Sensitive Vidicon - The development of a video detector that is sensitive to the spectral region longward of the magnesium fluoride cutoff at 1150 Å would be a useful device for both a solar line profile spectrometer and the UV-Vis/NIR spectrometer. The convenience of using a video detector over the handling problems associated with photographic film would make the video detector the preferable device for the solar instrument if the spectral resolution is adequate.

e. Infrared Detectors - Improvement of detector efficiencies in the infrared region would be a great aid in meeting scientific observation requirements on faint sources that are observed at high spectral resolution. The development of solid-state IR detectors will undoubtedly result in more sensitive devices by the time the ASF instruments are flown. The ability to fabricate mosaic arrays of detectors, with each detector having a separate amplifier, would facilitate the design of instruments that must operate with a wide variety of observing parameters, such as spectral resolutions and fields of view. Improved sensitivities of detectors operating with the Josephson effect may be offset by the complexity of the auxiliary apparatus required to operate the detector. The prospects look promising, however, for the development of infrared quantum counters that are tuned to detect only specific frequencies that correspond to atmospheric spectral lines of interest.

2. Synchrotrons

A strong request was put forth at the October 1972 ASF conference for extremely accurate in-flight calibration. One suggested way of calibrating absolutely was an onboard synchroton.

Synchrotron radiation emitted by highly energetic electrons is an excellent source of radiation, especially in the vacuum UV and shorter wavelengths, because of its continuous spectral distribution and high intensity, and the characteristics of the radiation can be predicted theoretically. Presently, at the University of Wisconsin, Physical Sciences Laboratory, a synchrotron is being used to calibrate optical instruments with an absolute accuracy of 5%.

A rough estimate indicates that a machine of 100 MeV energy with an 80-kilogauss field would have a cutoff wavelength of 200Å and an orbital frequency of 3 kilomegehertz (S-band). The spectrum extends from 200 Å longward.

The flight hardware to perform this function in an orbiting ASF would be perhaps 3 ft in diameter and 2 ft high. The weight of the synchrotron, excluding radio frequency supplies, magnetic current supplies, cryogenics, etc, would be under 2000 lb. Equipment for maintaining vacuum may be unnecessary, if the device were to be used only while the ASF were in orbit.

D. FUTURE ACTIVITIES

The present contract study was conducted on the premise that the ASF program would proceed along the lines indicated in Fig. VI-3, subsequently to be referred to as Option "A." This approach envisioned that ASF would be, to quote from the introduction to the September 1970 *ASF Scientific Objectives Conference* (MCR-71-334): ". . .a spectroscopic facility with interchangeable components to look at many parts of the spectrum, concentrating on atmospheric experiments." This concept is further delineated in the *Conclusion - Science Objectives Study* of the May 1972 *ASF Baseline Summary* (MCR-72-124), which states: "The ASF has generally been considered to be a spectrometric facility, possessing only passive systems." The Option "A" approach recognized that the completeness and the scope of the preliminary facility design that would result from the present contract study would depend directly on the input of scientific goals and requirements received from the scientific community. The Option "A" approach further envisioned that these inputs would be reasonably complete by April or May of 1972 and that the instrumentation requirements based on them could proceed to the instrument preliminary development phase in 1973, as defined in Task V of the present contract.

Enthusiasm in the scientific community and within the various NASA agencies did not stop in April or May, however, and has continued to grow and expand steadily ever since. It is becoming increasingly clear that these groups strongly favor expanding and re-directing ASF to go beyond the original concept of only a ". . .spectrometric facility, possessing only passive systems." It seems clear that the scope of ASF should be broadened to incorporate many of the "potential" additions into the expanded baseline. This should include the active laser systems, *in-situ* measurements, Earth surface observations (possibly with coorperative, and remote satellites mentioned in the Conclusions of the May 1972 *ASF Baseline Summary* (MCR-72-124) and in Sections II.E., IV.A.3., and VI.C. of this report.

If this is done, an experiment definition activity should be initiated at once to further study and define these new experimental areas and to bring them to the same level of definition as the Option "A" baseline. Such an approach has been identified in Fig. VI-4 and designated as Option "B". The Option "B" approach suggests that this definition phase extend into late 1973 and that the instrument preliminary development phase not start until then. This approach

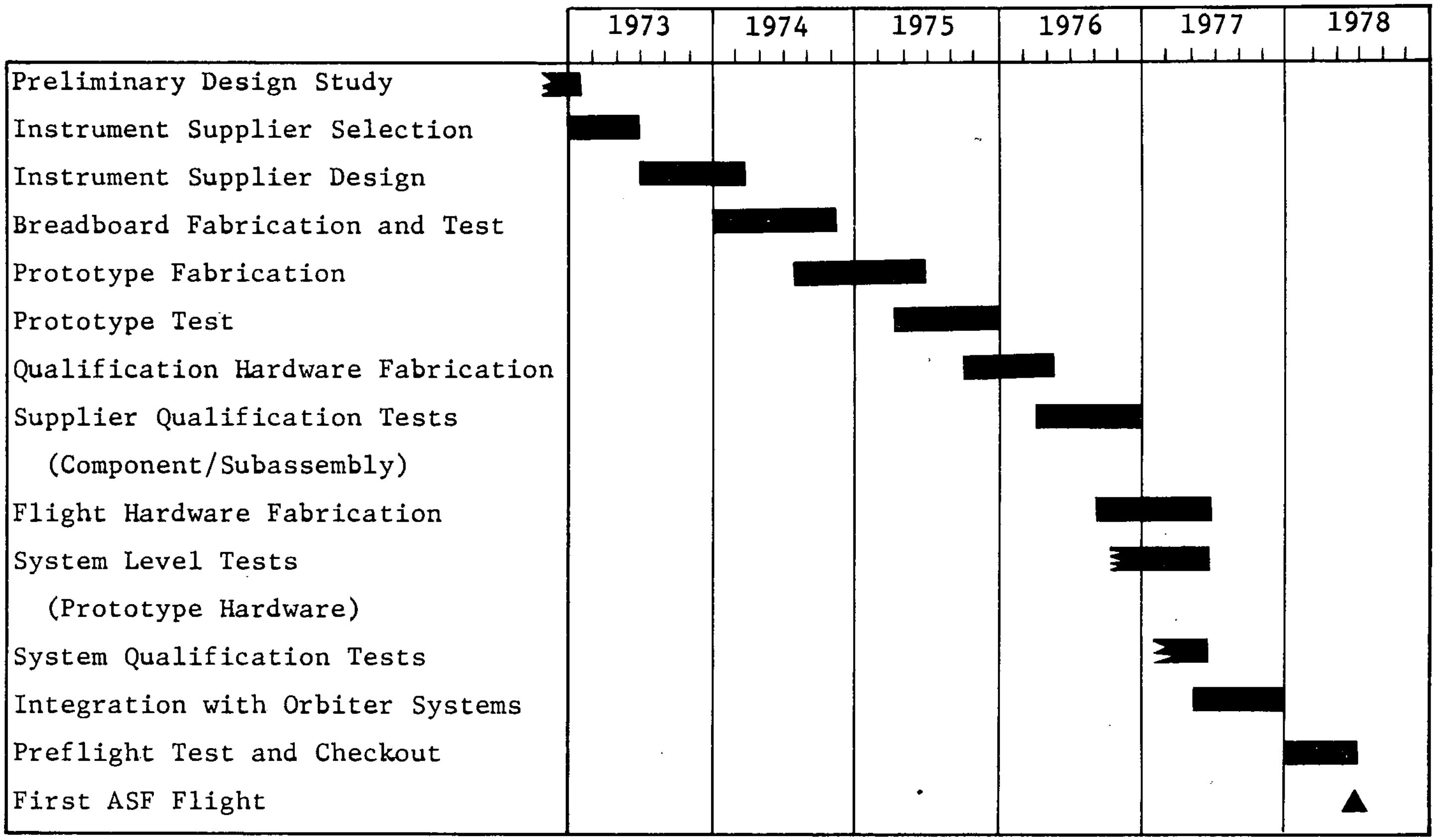


Fig. VI-3 ASF Instrument Progression, Option A Current ASF Baseline

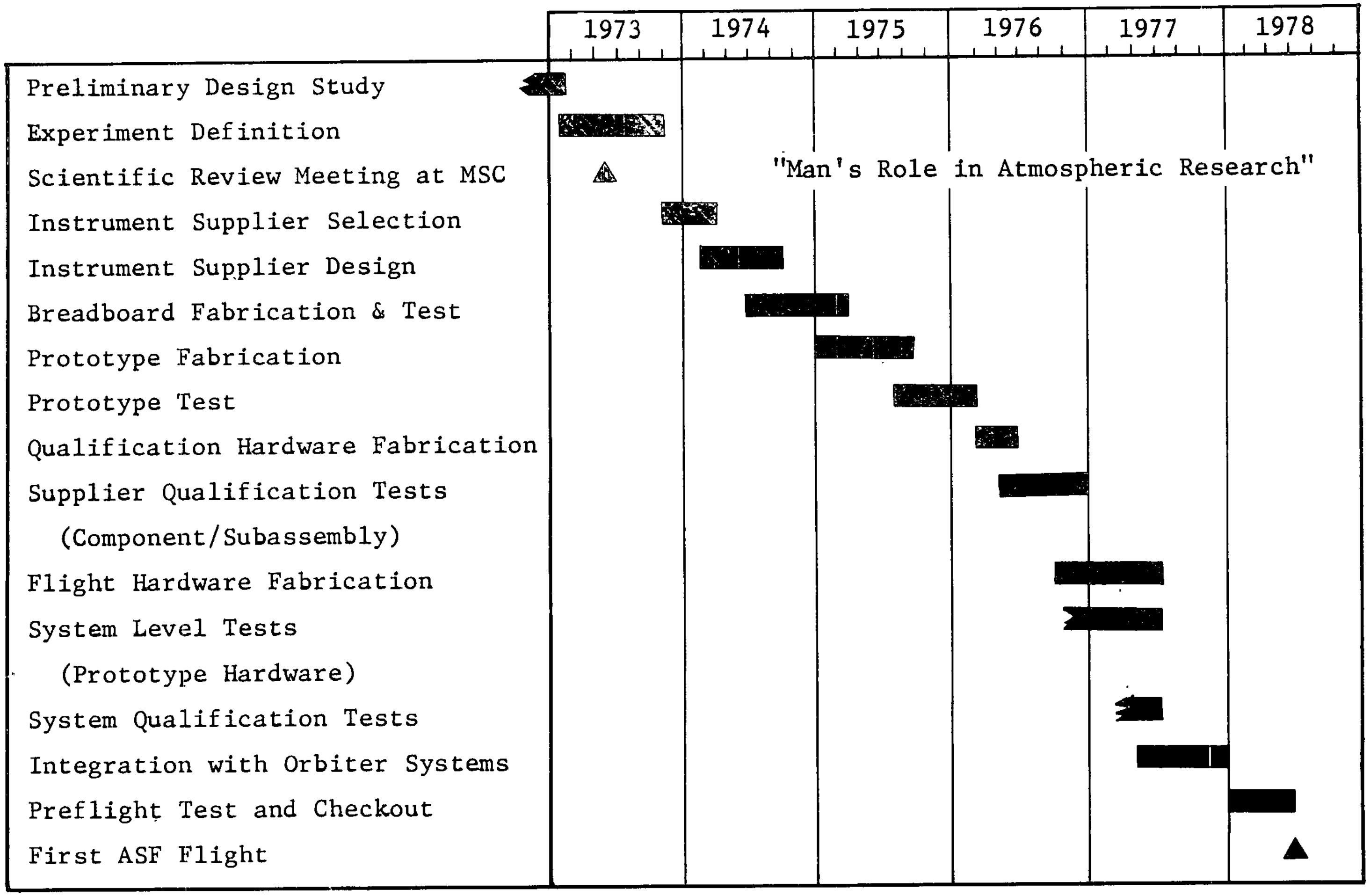


Fig. VI-4 ASF Instrument Progression, Option B Expanded ASF Baseline envisions a presentation and mid-point review of the expanded experiment definition by a scientific review meeting at MSC. This could be coordinated with, or included in, the proposed conference on "Man's Role in Atmospheric Research," which is scheduled for that same time interval. The Option "B" approach maintains the launch of a developmental ASF payload with the early developmental flights of the Space Shuttle in 1978.

VII. SUMMARY AND CONCLUSION

The Atmospheric Science Facility (ASF) Preliminary Design Study was initiated to establish scientific objectives; experiment types; preliminary instrument performance parameters; and preliminary designs of instruments, telescopes, and pointing controls for a reusable, manned, orbiting, general-purpose optical facility. A primary purpose of the ASF is research into problems of the terrestrial atmosphere by providing the opportunity for scientists to perform sophisticated experiments in orbit, using the instrumentation developed for the facility.

The sequence of tasks in the study is significant, in that the participation of the scientific community in the determination of objectives was solicited before the beginning of instrument preliminary designs, to ensure that the designs would provide for a maximum in scientific benefits. The material considered in the study, therefore, consisted of the contributions of approximately 40 scientists attending the 1970 ASF Science Objectives Conference at NASA's Manned Spacecraft Center (NASA-MSC), Houston, plus the responses to a detailed questionnaire sent to approximately 130 scientists in January 1972.

To provide the proper framework within which to analyze the responses, major goals and programs in atmospheric research were identified, using the recommendations of committees of scientists organized by the National Academy of Science and by NASA. Eight categories of objectives were derived from the responses, within each of which several areas of research on atmospheric phenomena existed, and for which a variety of measurement techniques could be applied.

A detailed analysis of all experiments suggested to accomplish the objectives was undertaken, in which specific instrumental performance parameters were identified. Constraints imposed on the ASF by the Space Shuttle Program were evaluated. Two types were identified--characteristics of the Shuttle Orbiter, and constraints resulting from performing observations in low-Earth orbit. Several of the Shuttle payload accommodations, derived from existing descriptions, could be restrictive and either require the inclusion of additional capabilities in the ASF design or efforts to improve the Shuttle services in the future. Orbital effects on the ASF are beyond control, and must be accommodated in the design and operation of the instrumentation. They are primarily geometrical and temporal in nature, imposing specific requirements in pointing and data rates, or in the choice of orbit. With the exception of "point-source" astronomical observations, or atmospheric observations of phenomena with characteristic time scales on the order of hours, all of the suggested experiments were considered in the preliminary designs.

Observational requirements were derived from the experiments. Simultaneity in spectral measurements was emphasized, and the requirements lead to the definition of at least three gimbal-mounted clusters of instruments to perform atmospheric, solar, and previewing observations, respectively.

A set of driving parameters for instrument design was developed for the principal observational techniques required over the full spectral range, by extracting the most stringent parameters specified in the experiments. These driving parameters represented the goals for the preliminary instrument designs, although the designs need not satisfy all of them at one time.

Design work for the preliminary instrumentation, telescopes, and pointing controls was initiated near the end of the scientific objectives study, beginning with the collection of material on the current state of the art for a number of instrument components, a baseline set of instrumentation employed in atmospheric and space astronomy studies, and the possibilities in pointing control and optical systems. Preliminary designs were performed to verify the feasibility of the facility concept with actual instruments; to identify design problem areas; to lead to concepts for the overall ASF configuration; and to provide a basis for iteration of the facility designs in later phases of the program.

The results of the study were presented in October 1972 at an ASF Science Review Conference at NASA-MSC, to which approximately 70 scientists were invited. Results of that conference were incorporated into an updated set of objectives and performance requirements. Several new research areas and techniques were suggested at the conference as well, and their requirements have been pursued in the subsequent period.

Man's role in the performance of the ASF was examined, with the expectation that personnel having a background in atmospheric science would be involved. The general conclusion that man possesses the capability to perform both manipulative and judgmental tasks in space as well as performed on the ground, given adequate hand and foot support, was upheld. The increase in flexibility and precision of experiments using the efforts of man was developed, and the anticipated variety of operations and instruments resulted in an optimum ASF crew size of three.

Data handling, test, and checkout requirements for the facility were considered. Because the expected mode of operation for the ASF is that of the Shuttle sortie mission of seven days, only a moderate amount of real-, or near-real-time transmission of data to the ground would probably be required, most of the data being stored on board until the end of the mission. Several points about the data system were emphasized; a sophisticated mode of data display to the experiment operator should be developed to aid in evaluating and directing the observations, the maximum of autonomy from the Shuttle data system is desirable, flexibility in the experiment mix requires a more complex processor than traditionally encountered in space vehicles, anticipated high data rates and data processing for display and evaluation would benefit from a large memory and a higher order (more symbolic) machine language, and the expected long-term evolution of the instrumentation aboard ASF demands the ability to verify new systems on the ground by checkout procedures fully compatible with the ASF system.

Preliminary configurations for the facility were produced considering a variety of requirements, including a shirt-sleeve environment for the ASF crew, interchangeability in the experiment mix, simultaneous observations in several spectral regions with instruments of (perhaps) large size, sophisticated data handling and experiment control, and others. These configurations are by no means final, but they represent a significant development beyond the concepts of the ASF at the beginning of the study.

The Earth's atmosphere is a complex and dynamic system, composed of both neutral and electrically charged particles, which participate in a multiplicity of interactions with each other and with the external interplanetary environment. It is maintained in a balanced state with respect to its sources and sinks of energy and the forces acting upon it, while responding to perturbations in a variety of periodic and aperiodic ways.

The atmosphere presents a dual challenge to science--an understanding of it is a stimulating problem of the first magnitude, and, in addition, there is a practical imperitive for assuring its continued quality and capability for supporting life on this spaceship Earth.

Research problems of both a fundamental and practical nature would be addressed by the Atmospheric Science Facility, using the unique attributes of the Shuttle delivery system of large payload weight and volume, ample electric power, several navigational and data handling services, and the flexibility of man onboard. An atmospheric studies program of this sort would provide a coordinated attack on current problems in atmospheric research, and promises significant advances in our knowledge of the atmosphere over the 1980s.

Appendix A

CONTENTS

APPENDIX A - PRELIMINARY DESIGN CONCEPTS FOR ASF INSTRUMENTS

This appendix summarizes pertinent details of the preliminary designs that were developed during this study. The main body of the report presents the results of the study in the form of preliminary performance requirements, making as little committment to specific designs as possible. Much was learned, however, from the exercise of designing actual instruments. A symbiotic relationship developed, in which the experimental requirements influenced the preliminary designs, while the designs assisted in the evaluation and development of a viable set of requirements.

The organization of the appendix follows that of the main body of the report, presenting instrumentation first, followed by instrument clusters, pointing and control. The material is presented in storyboard format, using previously prepared viewgraph information from former presentations. Therefore, some of the more recent developments in the study will not be included.

A. GENERAL-PURPOSE INSTRUMENTS

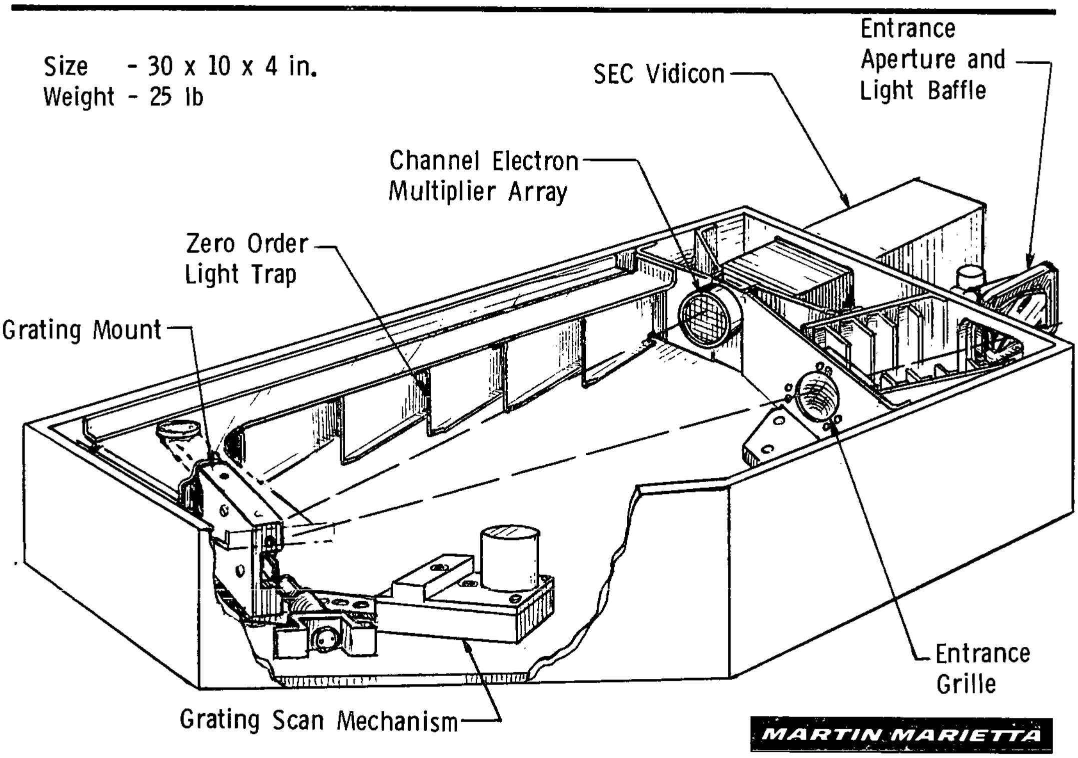
Four general-purpose spectrometers will be described (1) the XUV Normal-Incidence Spectrometer, (2) the UV-Vis/NIR Scanning spectrometer, (3) the SWIR High-Resolution Fourier Interferometer Spectrometer, and (4) the LWIR, FIR Cryogenically Cooled Fourier Interferometer Spectrometer.

1. XUV Normal Incidence Spectrometer

The irradiances of atmospheric sources are generally small in the extreme ultraviolet. Because ASF is on a fast moving platform and observation times are short, it is necessary to have a highly sensitive instrument. This study selected for feasibility evaluation a normal incidence concave grating spectrometer with a grille entrance aperture. The instrument's etendue is 1.2×10^{-3} sr cm^2. A Johnson-Onaka mounting was selected as yielding the best resolution over the desired spectral range of 300 to 1300 Å. The resolution was set at 10 Å, which satisfies experimental requirements while maintaining high light throughput. The instrument's field of view is rectangular, 10 deg on a side. The grating is the instrument field stop.

The detection scheme is the most interesting feature of this design. A phosphor channel electron multiplier plate converts the ultraviolet image to an electron image which impinges directly on the silicon photocathode of a SEC Vidicon television tube.

XUV NORMAL-INCIDENCE SPECTROMETER



a. Rationale For Grille Spectrometer Design - The most stringent requirement on the XUV spectrometer design is high sensitivity. Etendue can be increased by either increasing the entrance aperture size or the solid angle viewed by the instrument. Solid angle is fixed by resolution and field of view requirements so an enlarged entrance aperture was chosen - a grille consisting of alternate clear and opaque areas formed in a metal film. The area covered by the clear part of the grille is about 200 times as large as the area allowed by a slit.

An exit grille is also required, but the disposition of clear and opaque areas varies with wavelength. To avoid the inconvenience of changing exit grilles for different spectral regions, it was decided to form a two dimensional image of the spectrometer output on a television tube and to apply the exit grille electronically. The clear and opaque areas of the exit grille would be interchanged by electronic chopping to increase the signal-to-noise ratio. A phosphor and electron multiplier plate precedes the TV tube to convert the ultraviolet image to an electron image. The channel multiplier plate transmits about 60% of the incident light, and the entrance grille also absorbs half the light incident on it; but the overall transmittance gain of the system is about 120 compared with a slit spectrometer of equal resolution.

RATIONALE FOR GRILLE SPECTROMETER DESIGN

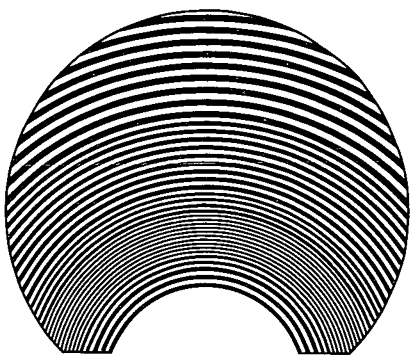
Primary Design Requirement - Sensitivity

Throughput Gain over Slit Spectrometer

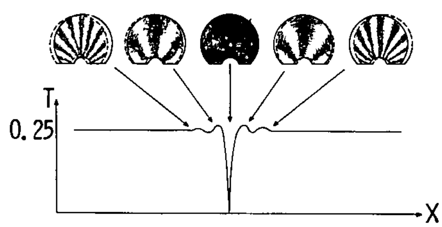
- Entrance Area Gain, ~200
- Electronic Chopping, ~2
- Channel Electron Multiplier Plate Area, ~0.6
- Entrance Grille Transmission, 0.5
- Increase in Overall Sensitivity, ~120

b. Circularly Symmetric Grille and Grille Scan Pattern - One possible form for an entrance grille is shown. The exit grille would have clear and opaque zones reversed. When the grating scans a single monochromatic spectral line the instrument response varies as shown in the lower sketch. For wavelength settings far from the spectral line, the transmittance of the spectrometer is 0.25. When the spectrometer is set right on the line the transmittance is zero for a "negative" exit grille and 0.5 for a "positive" grille.

CIRCULARLY-SYMMETRIC GRILLE AND GRILLE SCAN PATTERN



Schematic arrangement of zones on a circularly symmetric grille. Width of zones exaggerated relative to over-all size.



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c. Image Size for Selected XUV Spectrometer Mountings - There are several possible mountings for concave gratings. All meet the Rowland circle conditions approximately. Using equations from Samson's *Techniques of Vacuum Ultraviolet Spectroscopy*, the blur size due to aberrations alone was deduced. Diffraction was ignored. The Johnson-Onaka mount was analyzed for an included angle of 10 deg between incident and diffracted rays at the center of the grating. The numerical aperture of the beam was about 0.2, and the nominal best focus condition was set for λ = 600 Å. For the extremes of the wavelength range, the blur due to defocussing was entirely negligible. The Sega-Namioka mount was analyzed for two included angles: ∿70 and 25 deg. Best performance is predicted theoretically for the ∿70 deg case.

The best spectral resolution desired is 10 Å. The dispersion of the instrument requires a slit width of about 10 Å. The maximum acceptable blur circle was taken to be one-tenth the slit width or a blur circle size of about 100 μm. All of the mountings can easily achieve adequate image quality at least to a first approximation. Actual ray traces are desirable, but it appears that the choice of mounting can be made without concern about optical image quality.

IMAGE SIZE FOR SELECTED XUV SPECTROMETER MOUNTING

Spectrometer Mounting	Image Size (μm) 300 Å	600 Å	1300 Å
Johnson-Onaka (10°)	0.10	0.0	0.08
Seya-Namioka (~70°)	0.0	0.31	1.96
Seya-Namioka (~25°)	0.0	0.39	2.13
XUV Design Tolerance	~100	~100	~100

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d. Principal Features of Vidicon Detection Scheme - Video recording of Entrance Grille Images - Each XUV image of the entrance grille would be digitally recorded for computer processing at a later time to separate the images formed in different wavelengths.

Integration Capability - The SEC tube can integrate the signal for a period up to several minutes determined by the signal intensity and the dynamic range of the tube.

Electronic Chopping - By altering the polarity of the mathematical exit grille imposed on the computer image, two signal intensities may be extracted: one representing the entrance grille image of the desired XUV spectral line and one representing the background noise.

Elimination of Exit Grille - By recording on the vidicon the background noise that would be absorbed by the exit grille, more statistical counts are made available for analysis to determine the signal level. The instrument can also scan over a broader spectral range because optical aberations do not require the insertion of a new exit grille.

Computer Analysis of Video Images - Superposition of the mathematical exit grille and electronic chopping of the recorded video image is done in a digital computer. The intensities of the line under observation and the background noise are computed and the line intensity is determined.

PRINCIPAL FEATURES OF VIDICON DETECTION SCHEME

Video Recording of Entrance Grille Images

Integration Capability

Electronic Chopping

Elimination of Exit Grille

Computer Analysis of Video Images

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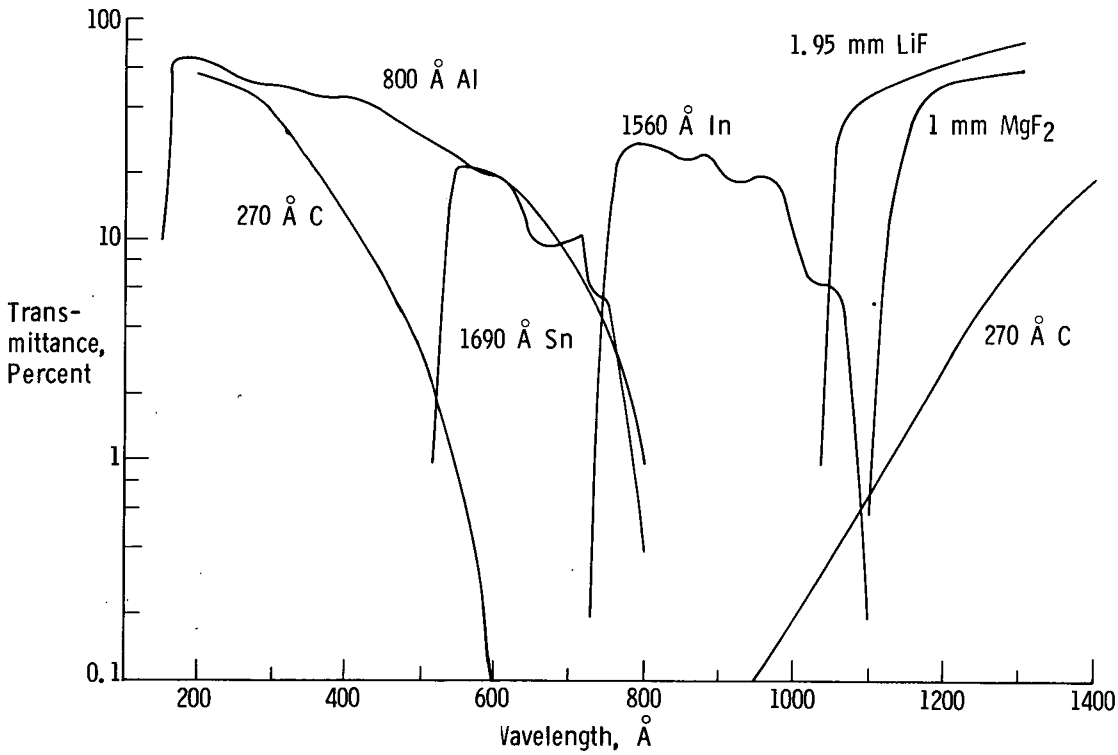
e. *Extreme Ultraviolet Transmittance* - Metallic thin film filters may be required to limit stray light in the instrument and control overlapping spectral orders. Filter technology at wavelengths less than the lithium fluoride cutoff is severely limited by the small number of materials that have satisfactory mechanical properties. The choice of wavelength ranges is therefore restricted. New filters may be developed in the next few years that will give higher transmissions and a better wavelength band definition.

EXTREME ULTRAVIOLET TRANSMITTANCE OF SELECTED METALLIC FILMS



f. Minimum Detectable Radiance - The calculated signal levels assume a background of 1 count/sec and a signal-to-noise ratio of four, and assume that there are no other spectral lines close to the one being detected. The minimum signal can be reduced if the integration time is increased; the minimum detectable signal increases as the square root of the integration time.

MINIMUM DETECTABLE RADIANCE AT SELECTED WAVELENGTHS

Wavelength (Å)	Integration Time (sec) 1	100
304	0.13 Rayleighs	0.013 Rayleighs
584	0.007 Rayleighs	0.0007 Rayleighs
1216	0.53 Rayleighs	0.053 Rayleighs

Minimum Detectable Signal Above Background (99% Confidence)

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g. XUV Calibration Approach - Ground Calibration - The calibration of an XUV instrument involves placing it in a vacuum chamber where a monochrometer feeds a spectrally pure beam to a collimation mirror that totally fills the aperture of the instrument. The intensity of the input beam is measured by a reference detector such as an ion chamber and compared with the instrument detector output. This is the best type of calibration that can be performed and will be done before and after flight.

Orbital Calibration - Although the equipment mentioned above could in principle be flown in space, it is quite cumbersome and difficult to operate. An alternative approach to orbital calibration is to use scattered sunlight to excite the instrument and to measure the instrument response. The absolute intensities of the solar radiation would be available from the solar monitor. This technique would not provide as accurate a calibration as the method suggested for use on the ground but should provide a relative check for instrument degradation.

XUV CALIBRATION APPROACH

Ground Calibration

- Gas Discharge Source and Monochromator
- State of the Art Accuracy
- Performed before and after Mission

Orbital Calibration

- Relative Check of Instrument Degradation
- Scattered Solar Radiation
- Relative Intensities from Solar Monitor

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h. XUV Normal Incidence Spectrometer--Control/Display - The investigator(s) aboard the Shuttle will be able to monitor and control the operation of the XUV spectrometer. The investigator will be able to set the wavelengths of the spectral region of interest and the scanning speed. A graphical display of intensity versus wavelength (or time) will allow him to estimate visually the signal-to-noise ratio of the spectrum and to make appropriate adjustments to the scan speed, vidicon gain, or integration time. Provision will also be made to place the spectrometer in a calibrator mode if a calibration source is on board.

XUV NORMAL INCIDENCE SPECTROMETER CONTROL/DISPLAY

Input

Wavelength Range

Scan Speed

Vidicon Gain

Camera Integration Time

Calibration Enable/Inhibit

Output

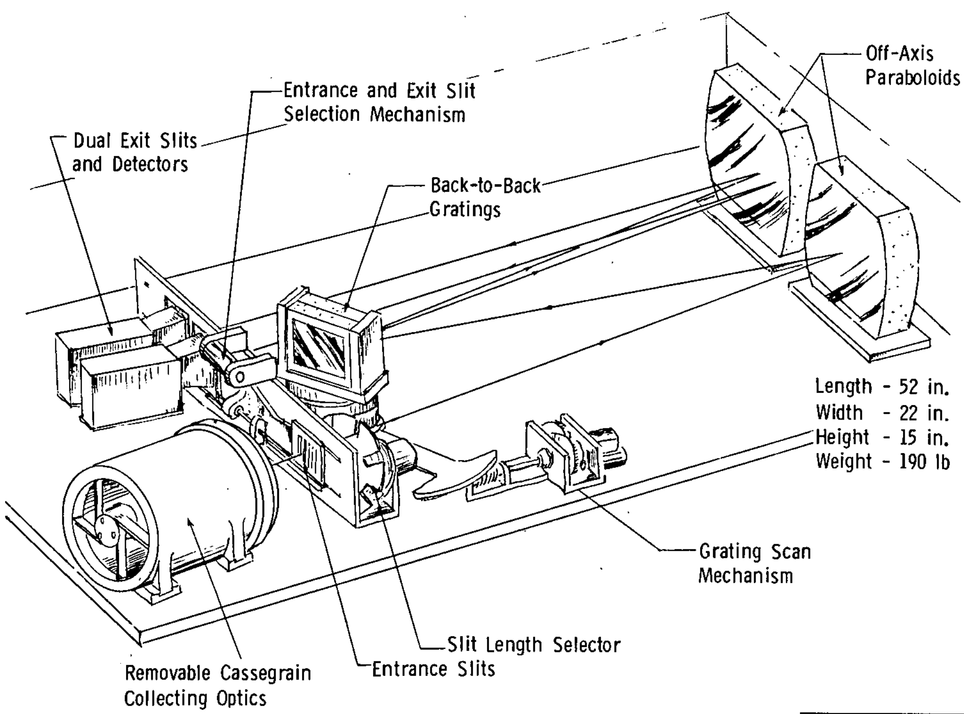
Intensity vs Wavelength

2. <u>UV-Vis/NIR Scanning Spectrometer</u>

The accompanying sketch shows the spectrometer design selected during the study. The instrument will meet the preliminary performance requirements, but is not an optimized design. In brief, the elements of the midrange spectrometer are a cassegrain collection optic used to restrict the instrument's field of view, a set of entrance slits of various widths, and a slit length selector that serves mainly to restrict the field of view. Two off-axis paraboloids are used for collimation and refocussing of the light. Two gratings are used interchangeably for different wavelength ranges. The first and second grating orders are used requiring dual sets of exit slits and detectors.

The entire instrument is about 52x22x15 in. and weighs 190 lb. Much of the weight is structural rather than optical, and no attempt was made to constrain size or weight.

UV-VIS/NIR SCANNING SPECTROMETER



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a. UV-Vis/NIR Scanning Spectrometer Design Specifications - The principal design specifications for the Czerny-Turner design considered in this study were coverage of the wavelengths from 1150 Å to about 1.1 μm. The wavelength precision goal was set at 0.1 Å. The resolution is adjustable depending on slitwidth, grating choice, and grating order--the finest resolution being 0.1 Å in the FUV; and the coarsest resolution, 85 Å in the longer wavelengths. The resolution is limited by geometrical optics and does not approach the theoretical resolution of the gratings. The relatively fast system f-number (f/5.2 x f/6.25) was selected to help maximize light throughout and is determined by the gratings that measure 128x154 mm and the focal length of 800 mm. The spectrometer has an adjustable field of view (the slit is the field stop for the instrument) when the cassegrain collector is in place. The cross-slit fields vary in steps from 16 arc sec to 38 arc min, and the slit length allows along-the-slit fields from 6 to 150 arc min. When the collector is removed the grating becomes the field stop and the field is approximately 9x11 deg.

UV-VIS/NIR SCANNING SPECTROMETER

Principle Instrument Design Specifications

Instrument Type:	Czerny-Turner Scanning Monochromator
Wavelength Range:	1150Å to ~1.0 μm
Resolution:	Selectable, 0.1Å to ~85Å
Focal Ratio:	
Focal Length:	800 mm
Field-of-View:	16 arc sec to 38 arc min with Collector (across slit) 6 arc min to 150 arc min with Collector (along slit) 9 x 11 degrees without Collector

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b. UV-Vis/NIR Scanning Spectrometer Operational Features - The principal feature of the design was high etendue. A large etendue is necessary for observations of sources of low intrinsic radiance when only limited observation time is available. Transmittance is also a factor that affects instrument sensitivity so allowance was made for removing the collector optics. Operation without the collector has two effects: (1) it eliminates the transmittance losses associated with the two reflections in the cassegrain and (2) it increases the field of view. The collector has a focal length of 575 mm and a diameter for axial rays of about 160 mm. If vignetting is prohibited, the collector diameter is increased to about 270 mm.

The Czerny-Turner employs two Baush & Lomb catalog gratings, each of 128 mm height and 154 mm ruled width. The gratings are remotely interchangeable. Detectors are also interchangeable to allow use of near-optimum detectors for each spectral region. To assure instrument versatility for a variety of experiments allowance was made for several slit widths and heights. Wavelength scanning rates and ranges were also allowed to be varied to suit particular experimental requirements. The primary detection mode was photomultiplier tubes, but photographic and TV recording of the output spectra are additional possibilities.

UV-VIS/NIR SCANNING SPECTROMETER

Operational Design Features

High Light throughput (étendue)

Removable Collector Telescope, 160 mm Aperture

Back-to-Back 154 mm Wide Gratings; Interchangeable

Interchangeable Detectors

Adjustable Slit Widths and Heights

Adjustable Wavelength Scanning Rates, Scan Ranges

Optional Photography of Spectra

Optional Video Detection

c. Grating Complement UV-Vis/NIR Spectrometer - It was determined that two plane gratings of different groove spacings were required to cover the desired spectral range. The gratings have 2400 and 830.8 grooves/mm for shorter and longer wavelengths, respectively. The gratings would be remotely interchangeable on command. The 2400 groove/mm grating has a nominal size of 128x 154 mm. Such a grating is not currently available, but may be available in time for ASF. Current gratings with 2400 grooves/mm are limited to ruled areas of 102x102 mm. Gratings of 830.8 grooves/mm are Bausch & Lomb stock items.

GRATING COMPLEMENT - UV-Vis/NIR Spectrometer

Plane Gratings

Mounted Back-to-Back

Remotely Interchangeable

2400 l/mm

Ruled Area: 102 x 102 mm (Eventually 128 x 154 mm)
Blaze Angle: 21.1 degrees
Spectral Range: 1050-2100 Å, 2nd Order
1800-4000 Å, 1st Order

830.8 l/mm

Ruled Area: 128 x 154 mm
Blaze Angle: 24.6 degrees
Spectral Range: 3000-6000 Å, 2nd Order
5000-11,000 Å, 1st Order

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d. Grating Scan Features - The gratings are rotated through an angle of 20 deg to scan the entire wavelength range and are driven by a stepping motor through a gear train. The grating angular increment is 0.001 deg for the finest spectral resolution (i.e, 0.1 Å in the FUV), and the stepping rate as provided by the stepper motor is variable from 0 to 500 steps/sec. Higher rates may be routinely available in the future but 500 steps/sec was selected as a reasonable estimate of current stepper capability. At the highest resolution the stepping rate corresponds to a grating scan rate of 0 to 0.5 deg/sec. Evidently a scan of the whole 20 deg will take 40 sec or more at highest resolution.

For user convenience the scanning of the grating can be from any initial position to any final position independent of scan direction.

GRATING SCAN FEATURES

Total Angular Range	20°
Angular Increment	0.001° (0.1 Å in Second Order with 2400 line/mm grating)
Stepping Rate	0 to 500 Steps per Second 0° to 0.5° per Second
Scan Time (Full Range)	40 sec at Least
Starting Position	Arbitrary
Length of Scan	Arbitrary
Direction of Scan	Either Way

e. Available Spectral Resolutions - The finest spectral resolution required for general-purpose experiments was 0.1 Å in the FUV. That requirement was taken as a driving parameter in the design. Coarser resolutions were also included to permit greater light throughput and reduced observation times. Obviously, the precise numbers derive from the particular geometry of the design chosen.

AVAILABLE SPECTRAL RESOLUTIONS

	Resolution Å			
	2400 line/mm		830.8 line/mm	
Slit Width (mm)	1st Order	2nd Order	1st Order	2nd Order
0.044	0.2	0.1	0.6	0.3
0.088	0.4	0.2	1.2	0.6
0.221	1.0	0.5	2.8	1.4
0.442	2.0	1.0	5.8	2.9
0.884	4.0	2.0	11.6	5.8
2.21	10.0	5.0	28.9	14.4
4.42	20.0	10.0	57.8	28.9
6.5	29.4	14.7	85.0	42.5

f. Fields of View Across Slit Width - Certain slit widths were required for the desired spectral resolution. Because the slit is also the instrument's field stop, the slit widths (and heights) correspond to particular fields of view when the collection focal length of 575 mm is taken into account. The largest slit widths are intended to increase light throughput, while the smaller slit widths (and fields of view) are selected to allow fine altitude resolution at the limb of the Earth.

FIELDS-OF-VIEW - ACROSS SLIT WIDTH

Slit Width (mm)	Field-of-View
0.044	15.8 arc sec
0.088	31.6 arc sec
0.221	79.4 arc sec
0.442	2.6 arc min
0.884	5.3 arc min
2.21	13.2 arc min
4.42	26.4 arc min
6.5	38.9 arc min

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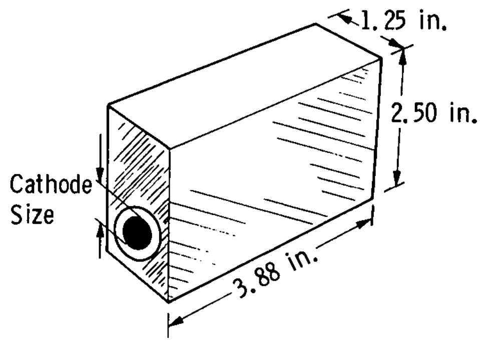
g. Detector Complement, UV-Vis/NIR Spectrometer - Four photomultiplier tubes were selected to cover the spectral range. The detectors are not optimized, and several of the detectors do not exhibit as much sensitivity as desired. It was felt that the photomultipliers chosen were typical of those available at this time.

DETECTOR COMPLEMENT - UV-VIS/NIR SPECTROMETER

Wavelength Range	Tube Designation	Cathode Material	Window Material	Effective Cathode Diameter (mm)
1150-1950 Å	EMR 510G	CsI	LiF	9.5
1800-4000	EMR 542N	Bi-Alkali	Fused Quartz	28
3000-6000	EMR 542E	Tri-Alkali	7056 Glass	28
6000-10,000	EMR 543C	S-1	7056 Glass	10.0



Typical EMR Integrated Detector/Power Supply

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h. Czerny-Turner Signal-to-Noise Ratio (SNR) vs Source Radiance - A typical, high-sensitivity photomultiplier was selected to illustrate the SNR for various source radiances and observation times. The graph shows the equation

$$SNR = \frac{\eta H A \Omega T t}{(\eta H A \Omega T t + N)^{\frac{1}{2}}}$$

where

η = detector quantum efficiency = 0.20

H = source radiance in photons sec^{-1} cm^{-2} sr^{-1},

A = entrance aperture area in cm^2,

Ω = input solid angle of field of view in sr,

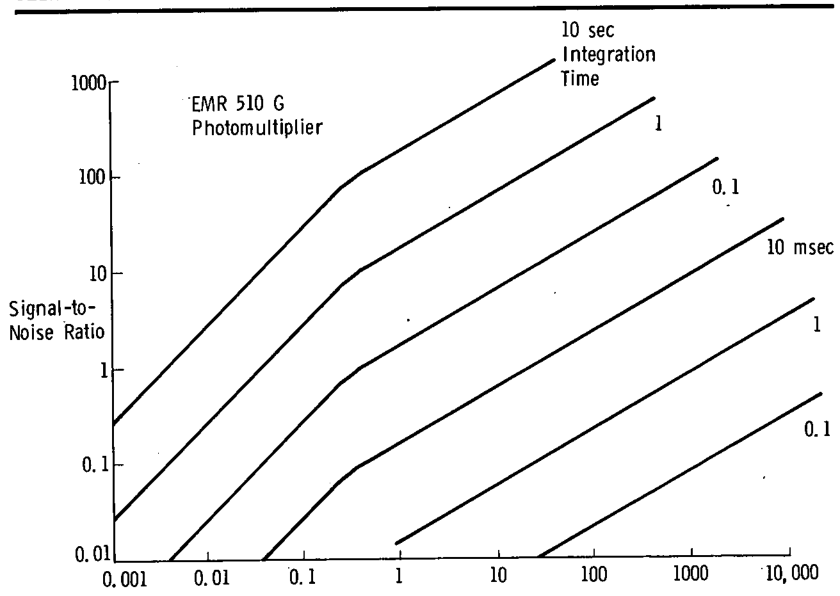
T = instrument transmittance,

t = observation time,

N = noise output in counts/sec.

At low source radiances the detector noise term dominates the noise. At high source radiances (above the "knee" of the curves) statistical fluctuations in the photon flux dominate the noise.

CZERNY-TURNER SIGNAL-TO-NOISE RATIO vs SOURCE RADIANCE



i. Photographic Detection for UV-Vis/NIR Instrument - An optional detection scheme allows a photographic camera to be used for longer wavelengths. Ordinary photographic films do not work in the ultraviolet without special handling techniques that were felt to be unnecessarily cumbersome. A standard Kodak film was chosen as an example. The film is quite insensitive compared to photomultiplier tubes and would probably be useful only for fairly intense sources. The camera was allowed to contain a film cassette holding 100 ft of polyester base film. The film would be driven behind an exit slit in synchronism with the scanning of the spectrum. A scan of the grating though its entire range would produce a spectrum about eight and a half inches long.

The film format was selected to allow recording of comparison spectra on either side of the sample spectrum, and two additional bands were included for recording of synchronism markers and housekeeping data, respectively.

A television system was considered as a detection option, but no detailed studies were performed.

PRINCIPAL FEATURES OF PHOTOGRAPHIC CAMERA

Format - 35 mm Perforated Film

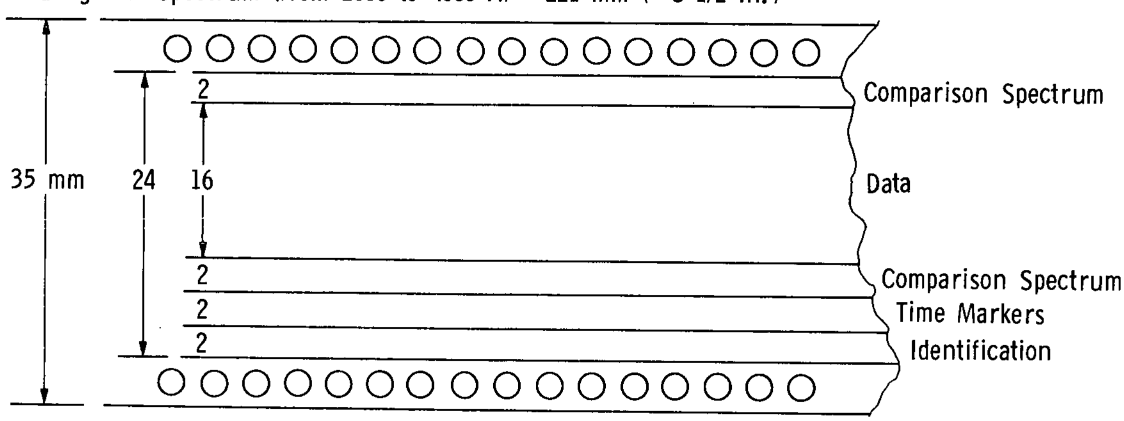
Film Type - EKC 1414 High Definition Aerial on Ultra Thin Polyester Base

Film Capacity - 100 ft or about 125 Complete Spectra

Drive - Variable Rate; Synchronous with Grating Scan

Wavelength Coverage - ~3000 to ~7000 Å

Length of Spectrum (from 2000 to 4000 Å) - 221 mm (~8-1/2 in.)



j. UV-Vis/NIR Scanning Spectrometer Control/Display - The operator on the Shuttle would have direct real-time control over the spectrometer and would be able to continuously monitor the output data. His selectable inputs would include spectral range scanning speed (Å/sec), resolution (Å), sensitivity (SNR per resolution element when the scan speed is programmed to permit a spectrum to be acquired at constant signal-to-noise ratio), grating choice (2400 or 830.8 grooves/min), slit height (mm and minutes of arc), camera or photomultipliers (as a detection option), and collector position. The operator's display would be observed intensity as a function of wavelength (or time).

UV-VIS/NIR SCANNING SPECTROMETER CONTROL/DISPLAY

Input

- Wavelength Range
- Scan Speed (Grating)
- Resolution
- Sensitivity
- Grating Selection
- Slit Height
- Flip Mirror
- Collector In/Out/Calibration

Output

- Intensity vs Wavelength

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3. Infrared Spectrometers

Two general-purpose spectrometers have been developed for the infrared. The following paragraphs present design goals, the rationale for two instruments, and a description of each instrument.

a. Infrared Design Goals - The full spectral range to be studied in in the infrared is the 1 to 150 μm region. Highest resolution requirements differ throughout that range, however. Specific requirements for minimum detectable signal have been identified for the 1 to 15 μm region, as well as the necessary dynamic range. The field-of-view range provides for high spatial resolution, as well as very high throughput for low signal sources.

INFRARED DESIGN GOALS

Total Spectral Range:	1 - 150 μm (10,000 - 67 cm^{-1})
Spectral Resolution (Maximum):	0.05 cm^{-1} (in 1-5 m region) 0.1 cm^{-1} (in 5-150 m region)
Minimum Detectable Signal:	$\sim 10^{-11}$ w cm^{-2} $Sr^{-1} \mu m^{-1}$ (in 1-15 m region)
Dynamic Range:	$\sim 10^{5}$ (in 1-15 m region)
Field-of-View:	Selectable, 3 arc min to 5 degrees

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Rationale for Two IR Instruments - To acquire the necessary spectrometric data in the infrared to study minor constituents, atmospheric structure, and reaction processes, simultaneous measurements are required in the 1 to 15 μm band. Time constraints and optical limitations dictate that two instruments are required. In addition, some investigators require data out to 150 μm at sensitivities that demand a cryogenically cooled instrument. These factors plus a less stringent resolution requirement in the longer wavelengths resulted in the decision for two instruments.

RATIONALE FOR TWO IR INSTRUMENTS

Simultaneous Coverage Required in 1-5 μm and 5-15 μm Spectral Bands

Different Instrumental Parameters Required in 1-5 μm and 5-150 μm Spectral Bands - Spectral Resolution/Sensitivity/Cooling

Component Change Capability in 5-150 μm Instrument - Detector/Beamsplitter/Filter

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b. High-Resolution-Fourier Interferometer Spectrometer Design Specifications - An instrument has been designed to collect spectrometric data in the 1 to 5 μm spectral region, with a maximum sensitivity of $\sim 10^{-11}$ w cm^{-2} sr^{-1} μm^{-1} (at 5 cm^{-1} resolution), and with a maximum spectral resolution of 0.05 cm^{-1}. A number of detectors are commercially available that will satisfy the sensitivity requirements. The instrument contains a series of field stops, permitting the selection of the field of view on command.

HIGH-RESOLUTION FOURIER INTERFEROMETER SPECTROMETER

Design Specifications

Spectral Band:	1-5 μm (10,000 to 2000 cm^{-1})
Spectral Resolution:	0.05 cm^{-1}
Detector:	Selected Photovoltaic (at 77°K)
Sampling Mode:	Step and Integrate
Scan Time:	$\lesssim$3 min
Field-of-View:	Selectable, 3 arc min to 5 degrees

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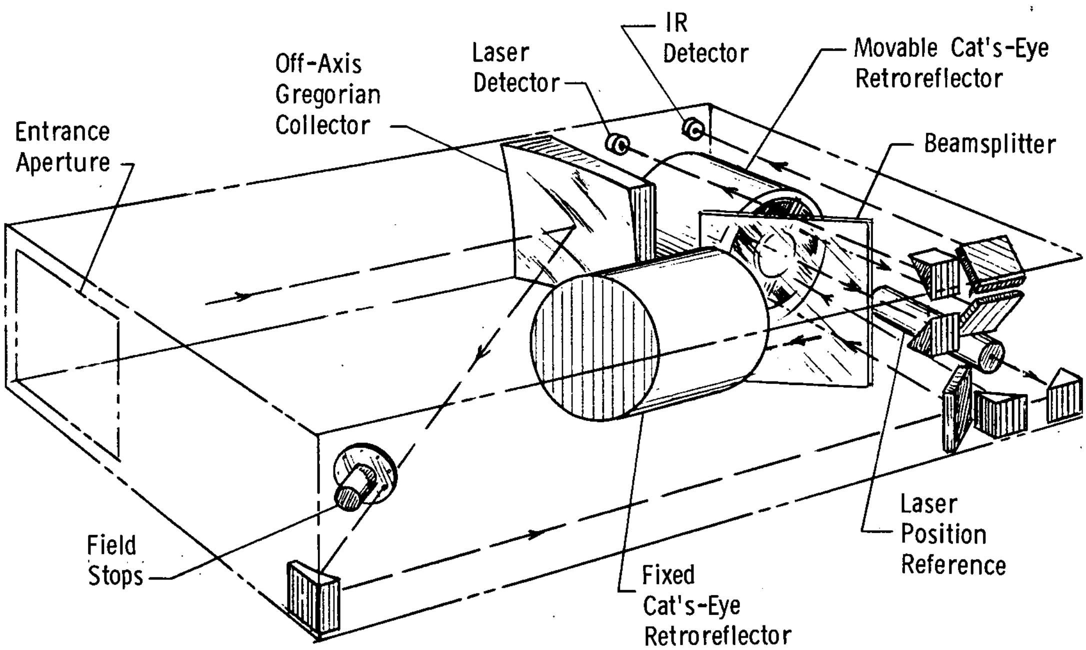
High-Resolution-Fourier Interferometer Spectrometer Optical Layout - The layout shown incorporates a number of the features discussed above. Off-axis Gregorian collecting optics focus incoming radiation onto an aperture wheel to define the field of view. Cat's-eye retroreflectors are used to compensate for misalignment, and to allow potential recovery of the conjugate beam through the use of a second detector. The reference laser beam travels the same path as the infrared radiation, but in opposite quandrants of the retroreflectors. Because size and weight constraints are less stringent than more conventional space hardware advantage could be taken of this concept. The estimated size for this instrument is 12x20x28 in. and estimated weight is 100 lb.

HIGH-RESOLUTION FOURIER INTERFEROMETER SPECTROMETER



Collecting Optics, 1 to 5 μm Instrument - In a high-resolution, high-sensitivity instrument, maximum throughput is critical. Elimination of central obscuration results in ∿25% greater input to the instrument. The literature discusses the off-axis rejection capabilities of the Gregorian system, and field definition can be established in front of the instrument. Relaxed size and weight constraints permit the use of off-axis collecting optics.

COLLECTING OPTICS - 1 to 5 μm Instrument

Off-Axis Gregorian System

Eliminates Central Obscuration

Stray Light Rejection

Field Definition at Entrance Aperture

No Severe Size Constraints

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Retroreflectors vs Flat Mirrors - One of the more difficult design problems encountered in interferometers is that of mirror alignment. The use of cat's-eye retroreflectors automatically compensates for mirror tilts. Initial fabrication costs are higher for cat's-eyes, and envelope size is a factor two higher, but the advantages gained are considered to be a fair tradeoff.

RETROREFLECTORS vs FLAT MIRRORS

RETROS	FLAT
High Cost (Fabrication)	Inexpensive
Large Size	Small Size
Ease of Alignment	Critical Alignment
Automatic Compensation for Tilts	Critical Control for Moving Mirror
Displaced Return Path	Superposed Return Path

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High-Resolution-Fourier Interferometer Spectrometer Control/ Display - The control and display features for the high resolution interferometer are shown below. Each function is a switch controlled input. The "cooler on/off" refers to a possible closed-cycle cryogenerator for detector cooling. The remaining functions are self-explanatory.

HIGH RESOLUTION FOURIER INTERFEROMETER SPECTROMETER CONTROL/DISPLAY

Input

- Field of View
- Cooler On/Off
- Scan On/Off
- Calibration Enable/Inhibit
- Calibration Temperature Selection
- Resolution
- Integration Time

Output

- Interferometer Diagnostics
- Intensity vs Wavelength

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Cryogenically Cooled Fourier Interferometer Spectrometer Design Specifications - Conceptually, the cryogenically cooled interferometer is capable of acquiring data in the entire 5 to 150 μm spectral region in perhaps, three discrete intervals. The instrument should incorporate interchangeable filter/beamsplitter/detector combinations. These components would be mounted before launch and would be fixed for the mission duration. Resolution requirements are less stringent for this instrument, but field-of-view definition is identical to the high resolution instrument.

CRYOGENICALLY-COOLED FOURIER INTERFEROMETER SPECTROMETER

Design Specifications

Spectral Range:	Total Range - 5 to 150 μm (2000 to 67 cm^{-1})	
	Selectable (Preflight)	
	Configuration A	2000 - 667 cm^{-1}
	Configuration B	667 - 200 cm^{-1}
	Configuration C	200 - 67 cm^{-1}
Spectral Resolution:	0.1 cm^{-1}	
Detector:	Ge Bolometer (at 4°K)	
Sampling Mode:	Step and Integrate	
Field-of-View:	Selectable - 3 arc min to 5 degrees	

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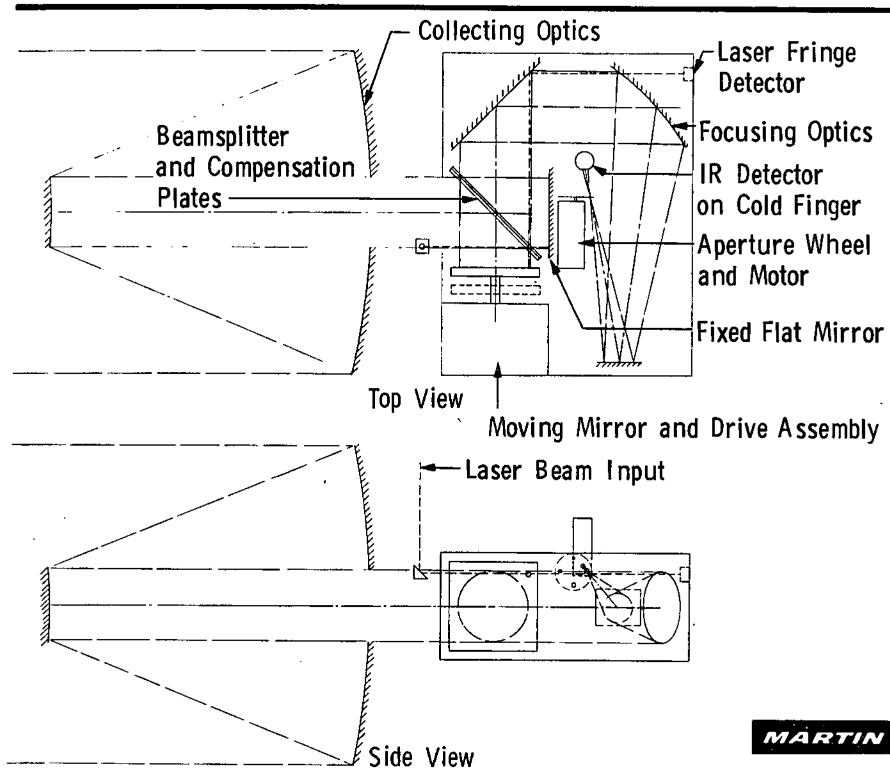
Cryogenically Cooled Fourier Interferometer Spectrometer Optical Layout - Shown are two views of a conceptual design of the cryogenically cooled interferometer. Efforts were made to keep sizes to a minimum. The instrument is a basic Michelson configuration, folded to permit size reduction. The entire instrument is enclosed in a dewar and arranged to permit cooling by both conduction and convection. The estimated size is 36 in. in diameter by 30 in. long and estimated weight is 250 lb.

CRYOGENICALLY-COOLED FOURIER INTERFEROMETER SPECTROMETER



Collecting Optics, 5 to 150 μm Instrument - The collecting optics for the cryogenically cooled instrument are designed to permit field definition between the exit aperture and detector. Self-emission will be one of the more critical problems associated with this instrument. Placing the aperture wheel inside the instrument will reduce emission from this source. An afocal cassegrain system is proposed because field definition is accomplished elsewhere. Because all surfaces in the instrument must be cooled, reduction of the instrument size to a minimum is critical.

COLLECTING OPTICS - 5 to 150 μm Instrument

Afocal Cassegrain - 10 inch

Minimize Cooling Requirements of Optics

Field of Definition at Exit Aperture

Size Limited

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Cryogenically Cooled Fourier Interferometer Spectrometer Control/ Display - Control and display functions for this instrument are quite similar to the high-resolution instrument. The functions must be remotely actuated because the operator would not have access to the cooled instrument.

CRYOGENICALLY-COOLED FOURIER INTERFEROMETER SPECTROMETER CONTROL/DISPLAY

Input

- Field of View
- Calibration Enable/Inhibit
- Calibration Temperature Selection
- Resolution
- Integration Time

Output

- Interferogram Diagnostics
- Intensity vs Wavelength
- Detector Temperature
- Instrument Temperature

B. SOLAR INSTRUMENTS

In addition to instrumentation for atmospheric observations, preliminary designs for required solar observations were developed. In what follows, descriptions of solar monitoring instrument for the XUV and UV spectral regions will be presented. Two types of measurements were treated--(1) moderate resolution, absolute intensity measurements and (2) high-resolution, relative intensity line profile measurements.

1. XUV-UV Solar Intensity Monitor Design Requirements

The solar spectrum would be observed by a set of grazing incidence monochrometers that cover the wavelength range from 170 to 1700 Å. The properties of optical materials in the ultraviolet (mainly low reflectivity) necessitate several instruments, each with an optimum design for a specific narrow wavelength interval. The required spectral resolution is 2 Å, and the measurement of solar radiance must be accurate to at least 5% absolute. A precision orbital calibration device must be included to assure the required radiometric precision. This study considered the use of a tungsten photo-diode or an ion chamber as a standard detector from which absolute radiance would be computed. High radiometric precision is important for determining variability in solar radiance over long periods. In addition, the solar intensity monitor would contain several fixed wavelength monochrometers for monitoring specific known emission lines.

XUV-UV SOLAR INTENSITY MONITOR - DESIGN REQUIREMENTS

Spectral Range: 170 to 1700Å

Spectral Resolution: 2Å

Intensity Accuracy: 1% Absolute

Instrument Array: Fixed Wavelength Monochromators (Specific Lines)
Scanning Grazing Incidence Spectrometers

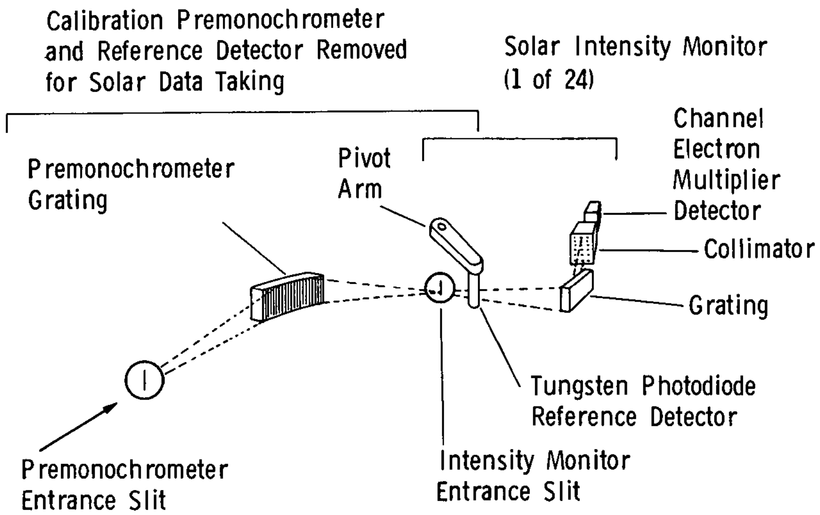
Orbital Calibration: Premonochromator
Reference Detector (Ion Chamber or Tungsten Photodiode)

Size: 24 x 12 x 12 in.

Weight: 30 lb

Solar Intensity Monitor Orbital Calibration Scheme - To calibrate the solar intensity monitor in orbit, basically two provisions are necessary. A premonochrometer provides a spectrally pure beam for the monochrometer to be calibrated, and a reference detector provides an accurate measurement of the intensity of the calibration beam entering the monochrometer. The spectral resolution of the premonochrometer must be slightly greater than that of the instrument to be calibrated. Protection of the reference detector from the effects of contamination is an important matter. This can be achieved by storing the detector in a heated chamber that is sealed from the environment when it is not being used for calibration.

SOLAR INTENSITY MONITOR ORBITAL CALIBRATION SCHEME



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2. XUV-UV Solar Line Profile Spectrographs

The profiles of the solar spectral lines would be measured to 0.02 Å with instruments that do not require the high absolute accuracy of the intensity monitor. Only relative intensities would be needed, but the spectra must be representative of the whole solar disk.

Because of the low flux levels and low reflectivities of optical surfaces in the XUV, the spectral range from 300 to 1700 Å must be covered with three instruments. A grazing incidence spectrograph would cover the region from 304 to the 584 Å helium lines. A two-grating, normal-incidence spectrograph would operate from 584 Å to the Lyman alpha line at 1216 Å. The region from 1150 Å to 1700 Å would be covered by a high-dispersion echelle spectrograph.

XUV-UV SOLAR LINE PROFILE SPECTROGRAPHS

Design Requirements

High Resolution (0.02Å)

Relative Intensity Measurements

Total Solar Disk

Spectral Coverage: 300 to 1700Å

Instrument Array

300 to 600Å: Grazing-Incidence Spectrograph

580 to 1220Å: Normal-Incidence Spectrograph

1150 to 1700Å: Echelle Spectrograph

a. Grazing Incidence Spectrograph Design Features - Wavelengths shorter than 600 Å would be observed with a grazing incidence spectrograph. The ray angles at the grating will be about 80 deg to assure high reflectivity. The grating has a radius of one meter and is used in orders from the 25th to 30th. High orders are employed to achieve high spectral resolution and dispersion. The high dispersion allows a fairly wide entrance slit that enhances light throughput. A thin, self-supporting, aluminum filter precedes the slit and absorbs long wavelengths. Photographic film was adopted as the primary detector in this preliminary design because the whole spectral band can be recorded in one exposure. The instrument field-of-view is about 35 arc min, and is determined by the grating which acts as a field stop.

GRAZING-INCIDENCE SPECTROGRAPH

Principal Design Features

High Reflectivity at Grazing Incidence Angle of 80°

Wider Entrance Slit - Greater Throughput

Thin Aluminum Filter - Long Wavelength Rejection

25th to 36th Order - Greater Spectral Resolution

1 Meter Radius Grating

Detector: Photographic Film

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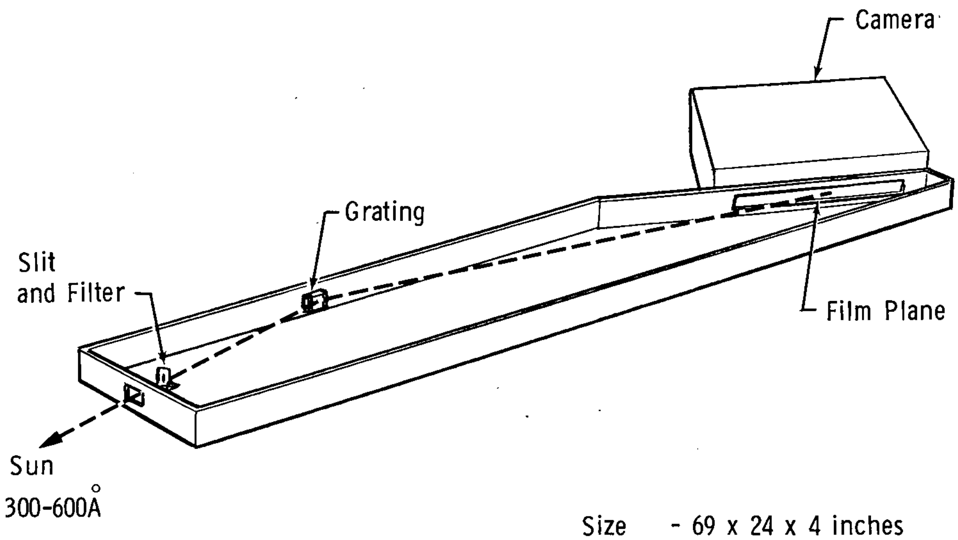
b. Grazing Incidence Spectrograph General Design - The sketch below indicates the general design of the instrument. The major portion of the weight (80 lb) resides in the camera that uses a pack of gelatinless sheet film. Films are developed after return of the instrument to Earth.

GRAZING-INCIDENCE SPECTROGRAPH



Size - 69 x 24 x 4 inches
Weight - 80 lb

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c. Normal Incidence Spectrograph Design Features - The wavelengths from 580 to 1220 Å are covered by a double monochromator. A predisperser grating of 0.4 m radius is used to facilitate stray light rejection and to define the wavelength range. The main grating has a 1 m radius and 2400 lines/min. The wavelength resolution is 0.02 Å. Two spectral subranges can be remotely chosen. Primary detection mode is also on XUV photographic film sheets. The field of view is determined by the entrance slit and is about 20 arc sec wide. The 1 m focal length of the instrument was chosen to match grating dispersion and resolution to the spatial resolution of the photographic film. The f-number is rather slow because of the size limitations of available gratings. The use of two reflections and the small entrance aperture lead to exposure times on the order of a minute even for a bright source such as the sun.

NORMAL-INCIDENCE SPECTROGRAPH

Principal Design Features

Predisperser Grating - Stray Light Rejection

1 Meter Radius, Main Grating

0.4 Meter Radius, Predisperser Grating

Two Spectral Ranges, Main Grating

- 580 to 920Å
- 880 to 1220Å

Detector: Photographic Film

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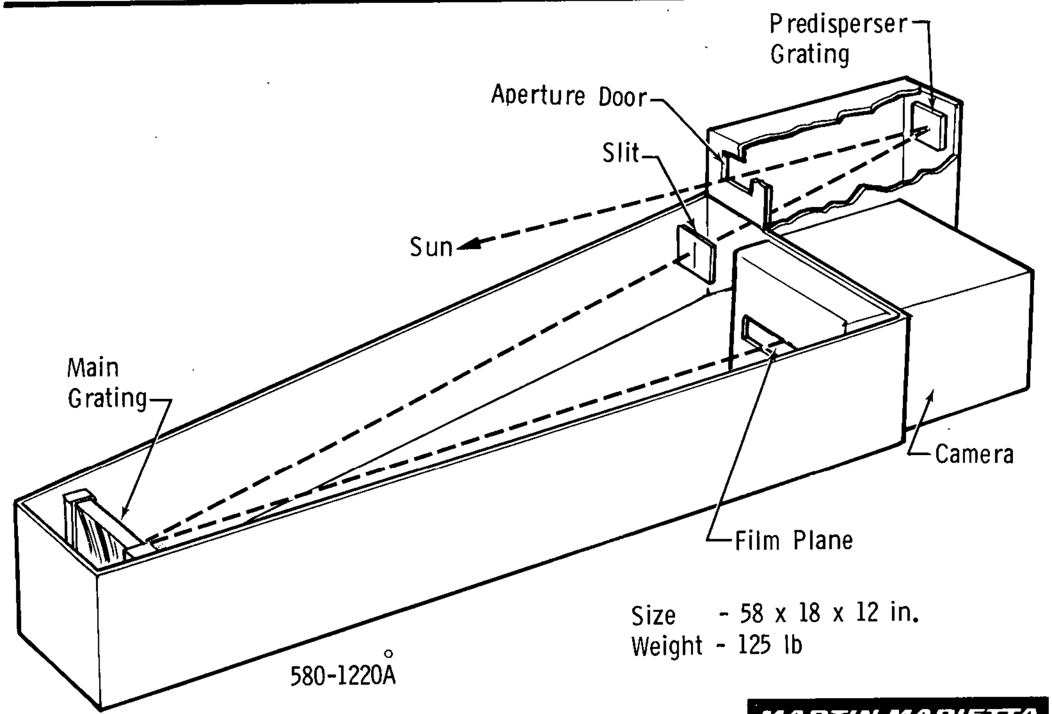
d. Normal Incidence Spectrograph - The sketch below shows a conception of the instrument. The dispersion of the predisperser grating is in the vertical plane. The dispersion of the main grating is in the horizontal plane. An aperture door would act as a shutter and would help prevent contamination of the predisperser. In the wavelength region for this instrument contamination of optical surfaces can have a drastic degrading effect on surface reflectivity.

NORMAL-INCIDENCE SPECTROGRAPH



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e. Echelle Spectrograph Design Features - A predisperser grating of 0.4 m radius is used to reduce stray light from longer wavelengths and to separate the orders from the main echelle grating. The optical reflectivity of magnesium fluoride overcoated aluminum is high enough in the 1150 to 1700 Å wavelength range to allow the extra reflections from the collimating mirror required by the echelle design. This would result in a compact instrument that has the high dispersion spectra separated horizontally by the echelle grating and the echelle orders separated vertically by the predisperser grating. This format would be compatible with the use of an ultraviolet sensitive vidicon as the detector, which would result in a significant increase in the ease of data handling when compared with photographic film. This instrument would not be able to cover the entire wavelength band with one exposure, however, and would have to be aligned before flight for the wavelengths to be observed.

ECHELLE SPECTROGRAPH

Principal Design Features

Predisperser Grating - Stray Light Rejection

Compact Instrument

Convenient Data Format

Detector: UV-Sensitive Vidicon

Limited Wavelength Coverage - Preflight Selection

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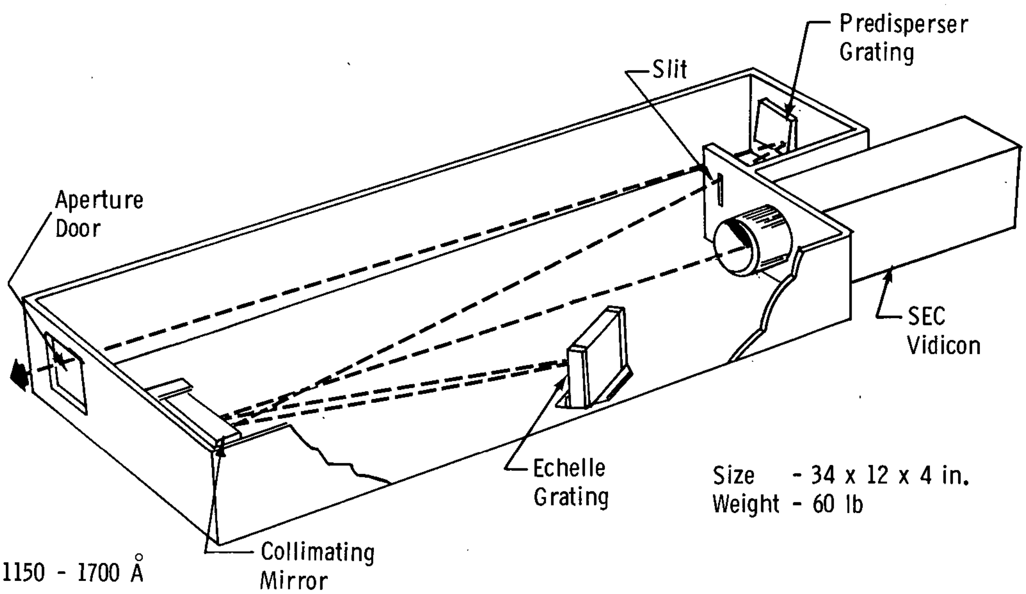
f. Echelle Spectrograph - The echelle optical design gives high dispersion in a compact instrument, because of the high dispersion of the grating and the folding of the echelle orders in the vertical direction by the predisperser grating. This convenient image format matches the faceplate of an ultraviolet sensitive SEC vidicon that offers the advantages of electronic data handling rather than the processing of photographic film.

ECHELLE SPECTROGRAPH



Size - 34 x 12 x 4 in.
Weight - 60 lb

1150 - 1700 Å

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C. SPECIAL-PURPOSE INSTRUMENTS

Two instrument types for atmospheric studies received preliminary design consideration during the study. They are (1) the filter photometer, and (2) the UV-Vis documentation camera. The following sections present further details on the preliminary designs of these instruments.

1. Filter Photometers Design Objectives

Filter photometers would be used for previewing and monitoring of atmospheric emissions that occur in well-known spectral regions where very high spectral resolution is not required. Some of the measurements that are possible are tabulated below. The one kind of measurement for which filter photometers are uniquely suited would be solar or stellar occultations.

FILTER PHOTOMETERS - DESIGN OBJECTIVES

Previewing/Monitoring of Atmospheric Emissions

Simultaneous Broadband Measurements

- Neutral Density
- Aerosols
- Ozone
- Molecular Oxygen

Atmospheric Scattering, Absorption, Emission Processes; Atmospheric Structure

- Horizon Scans
- Stellar Occultation

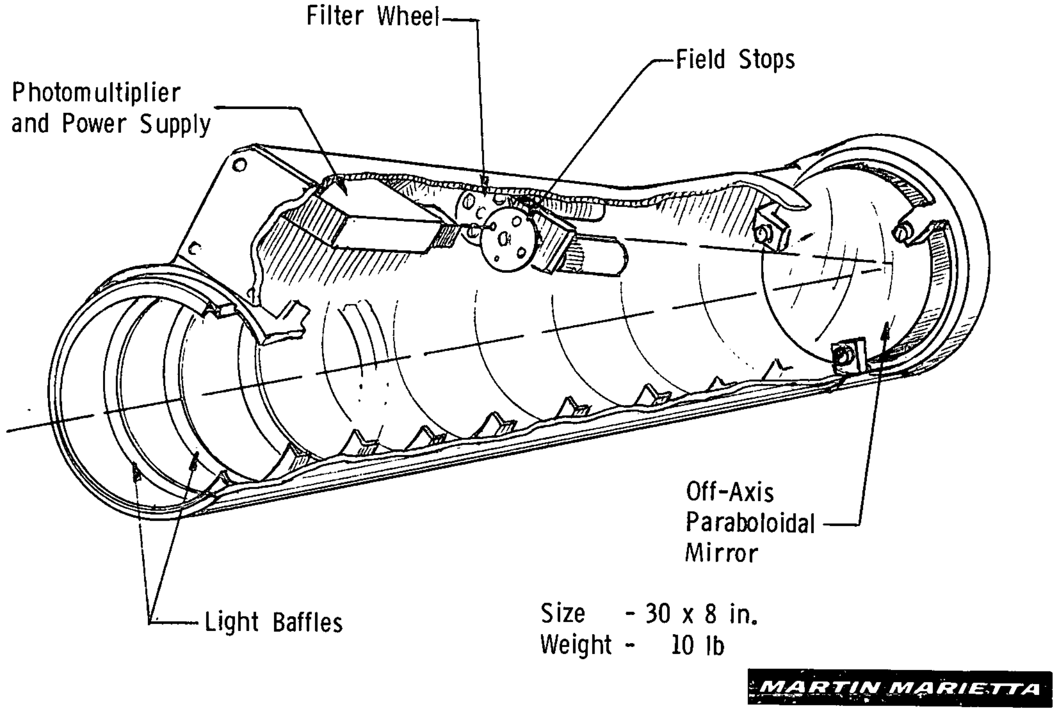
a. Filter Photometers Principal Design Specifications - The photometers consist of a single optical element: a 152-mm diameter off-axis paraboloid operating at about f/3. The single reflection allows its use over a very wide spectral range, and minimizes changes for stray light. The four photometers proposed for the main instrument cluster cover the wavelengths from 1050 to 8000 Å and differ only in their complement of interference filters and detectors. Each photometer contains four selectable filters having bandpasses of about 15 Å. A set of field stops is also provided at the focal plane to control the field of view.

FILTER PHOTOMETERS - PRINCIPAL DESIGN SPECIFICATIONS

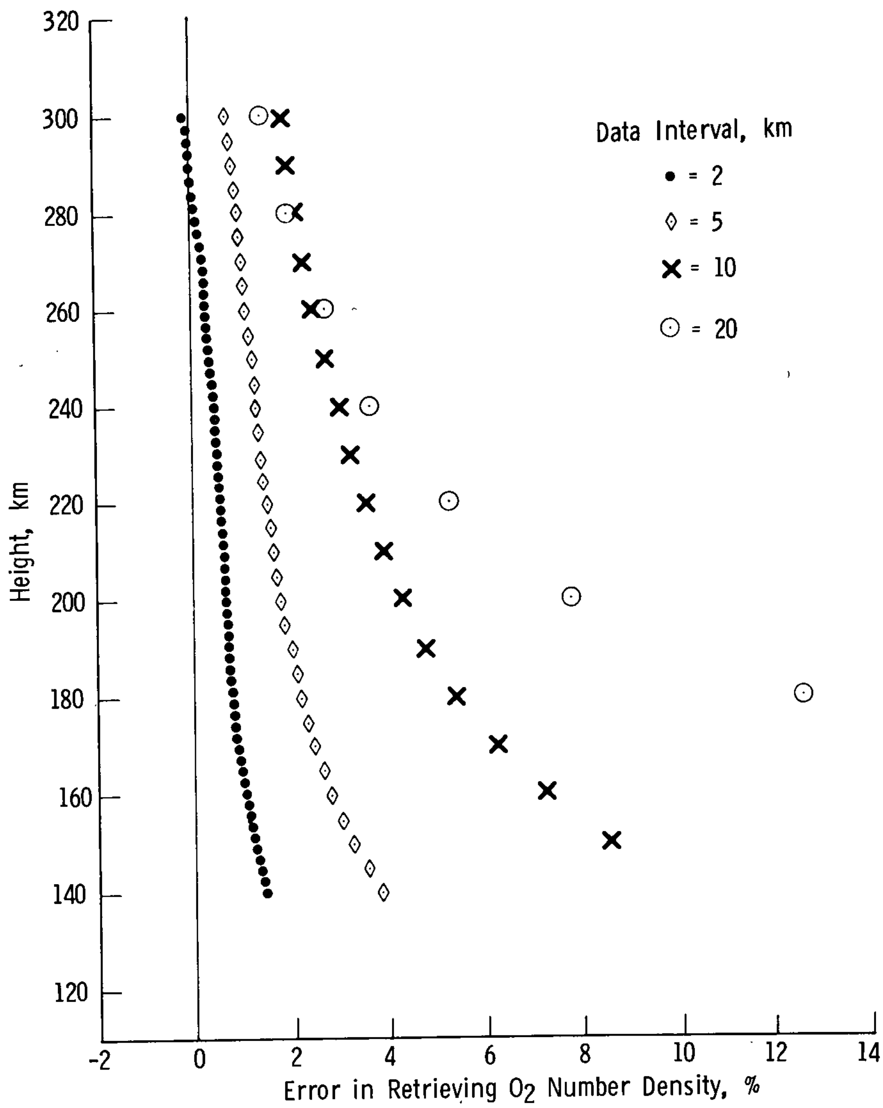
Collecting Optics:	Off-Axis Paraboloid (152 mm Aperture)
Focal Ratio:	~f/3
Total Wavelength Range:	1050 to 8000Å (With Four Instruments)
Wavelength Resolution:	~15Å; Selectable Interference Filters (4 per Unit)
Field-of-View:	Selectable (1 arc min to 1 degree)

b. Filter Photometer - Below is a sketch of the preliminary design for a filter photometer. The relatively small size and weight of individual photometers allows a large number of them to be included in the instrument clusters.

FILTER PHOTOMETER



c. High Data Rate Required for Occultation Measurements - High sensitivity and fast response are required from the filter photometers when they are used to do atmospheric height profiling by observation of stellar occultations. The line of sight of the photometers moves through the atmosphere at the limb at some 2 km/sec. It is desirable to obtain several data points per kilometers with an adequate signal-to-noise ratio. These requirements have most strongly influenced the photometer design.



High Data Rate Required for Occultation Measurements

d. *Filter Sets Required for Neutral Density, Ozone, Aerosol, Molecular O_2 Experiments* - An example of a set of filters is given below. The filters shown could be used to deduce distributions of ozone, molecular oxygen, aerosols, and neutral density. The four photometers would be used simultaneously. Other filter sets could be selected for other experiments.

FILTER SETS REQUIRED FOR NEUTRAL DENSITY, OZONE, AEROSOL, MOLECULAR O_2 EXPERIMENTS

Photometer	Filter Set (1)	Filter Set (2)	Filter Set (3)	Filter Set (4)
A	3371 Å	2150 Å	1500 Å	Unspecified
B	3914 Å	2600 Å	1900 Å	Unspecified
C	5577 Å	2850 Å	2000 Å	Unspecified
D	7000 Å	3100 Å	Unspecified	Unspecified
Experiment	Neutral density, aerosols and ozone	Ozone and neutral density	Molecular O_2 and neutral density	Unspecified

Filters can be selected for dayglow, nightglow, and aurorae experiments

e. *Instrument Signal-to-Noise Ratio vs Source Radiance* - The table below shows the calculated signal-to-noise ratio for the four photometers. The computations assumed the largest field of view (1 deg diameter) and assumed that the filters each had a transmittance of 0.50. All the figures are approximate.

INSTRUMENT SIGNAL-TO-NOISE RATIO vs SOURCE RADIANCE

PMT Type	Dark Count Rate (Counts per Sec)	Quantum Efficiency Q.E.	Quantum Efficiency Wavelength (Å)	Signal-to-Noise Ratio (10 msec Integration) Source Radiance = 0.1 R	Signal-to-Noise Ratio (10 msec Integration) Source Radiance = 10.0 R
EMR 542 F-08	250	0.003	3371	1.9:1	57:1
		0.06	2150	22	260
		0.05	1500	19	230
EMR 542 N-08	60	0.10	3914	33	330
		0.13	2600	38	380
		0.17	1900	43	430
EMR 542 N-06	125	0.01	5577	10	100
		0.14	2850	39	390
		0.17	2000	43	430
EMR 542 R-01	3500	0.03	7000	4	171
		0.22	3100	31	489

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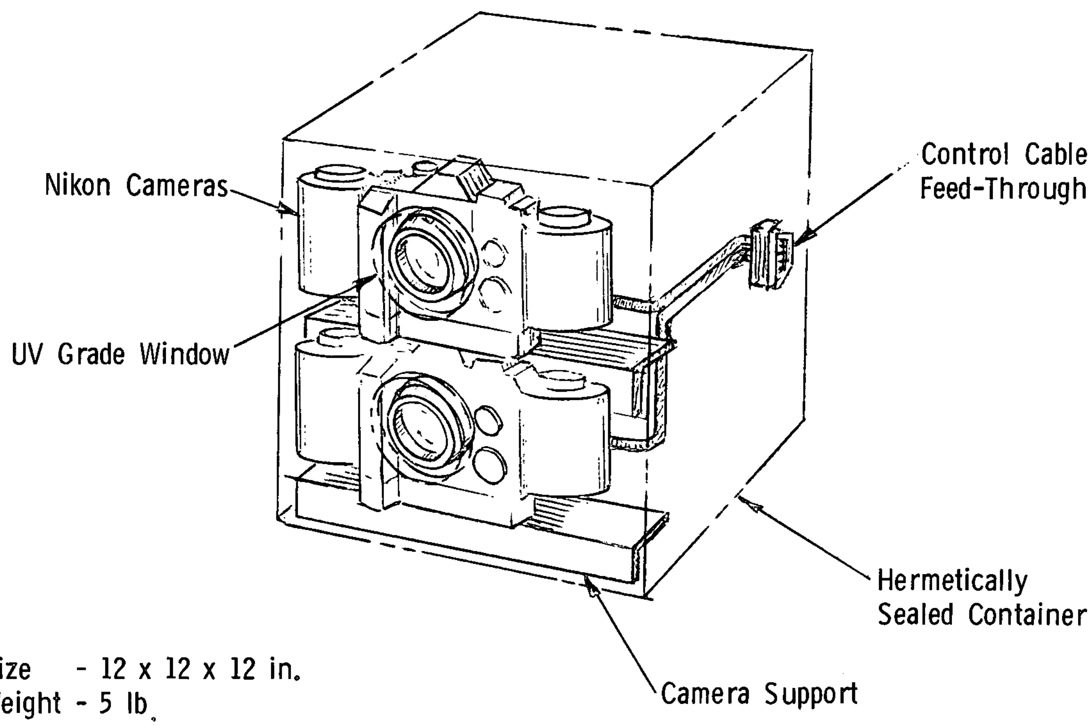
2. UV-Vis Documentation Cameras

A permanent record of the area observed by the main instrument cluster would be made by two or more documentation cameras. The cameras are modified commercial Nikon 35-mm single-lens reflex cameras. Nikon cameras are available with a 85-mm focal length lens that produces good image quality from ultraviolet to the far red. The lenses cannot be used over the entire spectral region at once because the focal length depends on wavelength. Over a 300 Å bandwidth, however, the lenses are of good quality. The cameras would be in a sealed box which maintains a proper temperature and humidity environment for the photographic film.

UV-VIS DOCUMENTATION CAMERAS



Size - 12 x 12 x 12 in.
Weight - 5 lb

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a. UV-Vis Documentation Cameras - Two cameras at least would be required: one primarily for ultraviolet, the other for visible light. Bandpass interference filters would be placed in front of lenses, and a selection of interchangeable filters would be available. The nominal filter passbands are ±250 Å centered on the selected wavelength of interest. Film format of 24x36 mm with an 85-min focal length lens gives a field of view on the order of 30 deg. That field would encompass the field seen by the main instruments and show features adjacent to the areas where spectrometric and photometric data are acquired. Film negatives containing 800 exposures are presently available. The motor drive on the Niken allows as many as five exposures/sec.

UV-VIS DOCUMENTATION CAMERAS

Principal Design Specifications

Two 35 mm Cameras

Wavelength Range:	UV - 2400 to 7000Å Visible - 3500 to 7000Å
Wavelength Resolution:	Filters (±250Å)
Field-of-View:	~30 degrees
Number of Exposures:	Up to 800 (at Five per second)

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b. *UV-Vis Documentation Camera Applications* - Applications for these cameras would include providing wide field records for mapping purposes of ozone "clouds," or for studies of the morphology of aurorae or the airglow in several possible wavelength bands. In addition, documented records of aerosol layers, or high-altitude clouds at the horizon would be possible.

UV-VIS DOCUMENTATION CAMERAS - APPLICATIONS

Mapping Ozone "Clouds" - ±250 Å Filters Centered near 2600 and 3200 Å

Coverage of 5577 and 6300 Å Atomic Oxygen Emission Lines

Mapping of 3914 Å N_2^+ Airglow/Auroral Emissions

Documenting Aerosol and/or High Altitude Clouds at Horizon

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D. GIMBAL MOUNTS, POINTING AND CONTROL

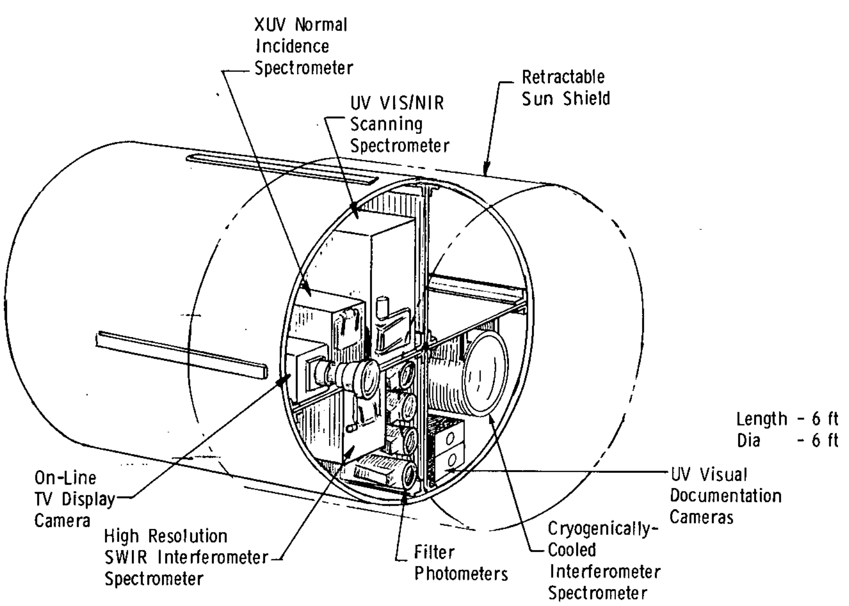
The following three subsections present the preliminary designs of the ASF instrument clusters, and their associated systems for pointing and control. They are: (1) main instrument cluster, (2) solar monitor, and (3) previewer.

1. Main Instrument Cluster

The general-purpose spectrometric instruments, on-line TV display, photometers, and documentation cameras are all boresighted to a common line of sight and are all mounted to a single structure. The mounting is to a rigid cruciform that provides a large mounting surface and easy access to individual instruments. The cluster is enclosed within a can that has an extendable sun shield. One quadrant of the cluster has been left open to allow for additional, special-purpose instruments and so-called "suitcase" carry-on experiments. The instruments are placed loosely in the cluster to provide easy access for replacement of obsolete instruments during the useful lifetime of the Facility.

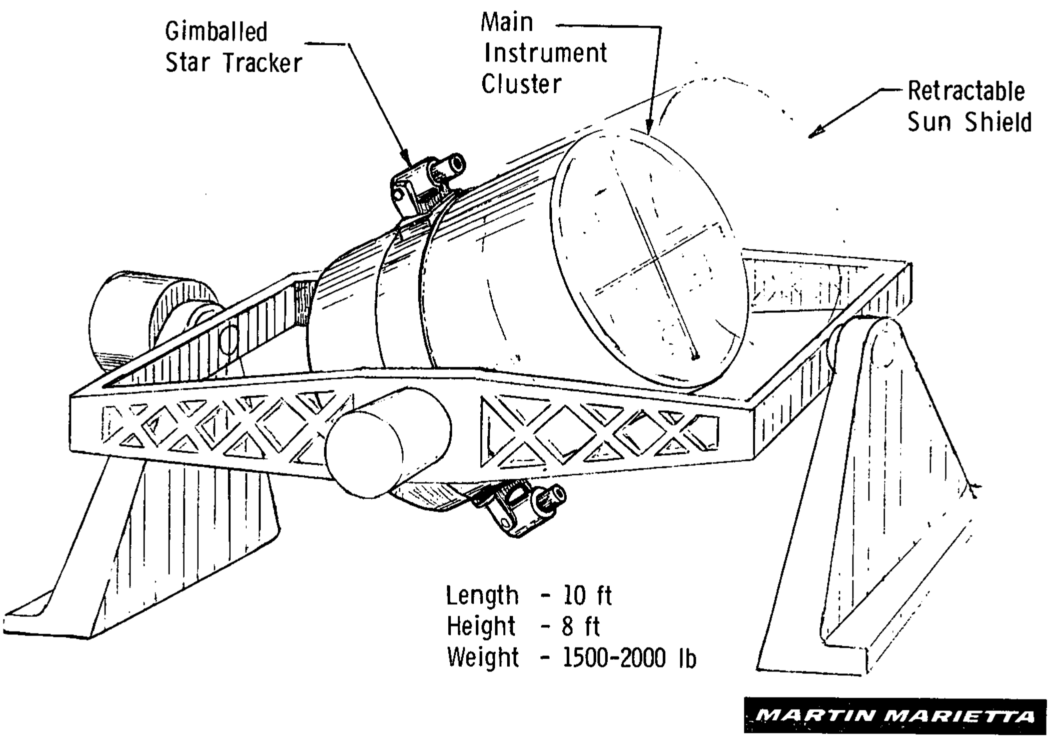
The overall dimensions are 6 ft long by 6 ft in diameter. The length is increased to ∿8 ft when the sun shield is extended.

ASF MAIN INSTRUMENT CLUSTER



a. Main Instrument Cluster and Gimbal - The cluster of instruments would be mounted on a three-axis gimbal system. The gimbals are driven by torque motors, which receive signals from a special ASF guidance computer. The guidance inputs are derived from a rate-stabilized gyro inertial reference, which is periodically updated (∿2 hr) by star tracker sightings.

MAIN INSTRUMENT CLUSTER AND GIMBAL



b. Main Instrument Cluster Pointing and Control - The most stringent pointing requirements are derived from the experiments that perform height profiles at the horizon. The desired height resolution is about 2 km from a range of 2400 km. The stability requirement is needed for performance of height profiling by observing stellar occultations.

The control system as envisioned now consists of an inertial platform employing rate stabilized gyroscopes with updating from star trackers. The estimated capability meets our requirements.

MAIN INSTRUMENT CLUSTER POINTING AND CONTROL

	Requirement	Capability
Absolute Pointing	3 arc min	3 arc min
Relative Pointing	20 arc sec	15 arc sec
Stability	2 arc sec	2 arc sec

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c. Input Data to ASF from Shuttle - The Shuttle attitude control system gives the angular orientation of the Shuttle in space and also the latitude and longitude of the subsatellite point and the altitude. Those data provide raw inputs to the ASE guidance computer. Some ASF considerations (e.g., location of scenes on the Earth) can be satisfied by Shuttle data but others (e.g., pointing direction) require outputs from the ASF own pointing system.

ASF star trackers are initialized from Shuttle data, but the guidance computer generates actual gimbal commands. The main instrument cluster operator is also provided with a "joystick" steering lever that will override preprogrammed guidance commands. The operator can take advantage of the TV cameras on the main instrument cluster and on the previewer in deciding to override programmed pointing.

INPUT DATA TO ASF FROM SHUTTLE

Attitude of Shuttle - Raw Data to ASF Guidance Computer from Shuttle Avionics

- 3 Axes
- North, East, Vertical

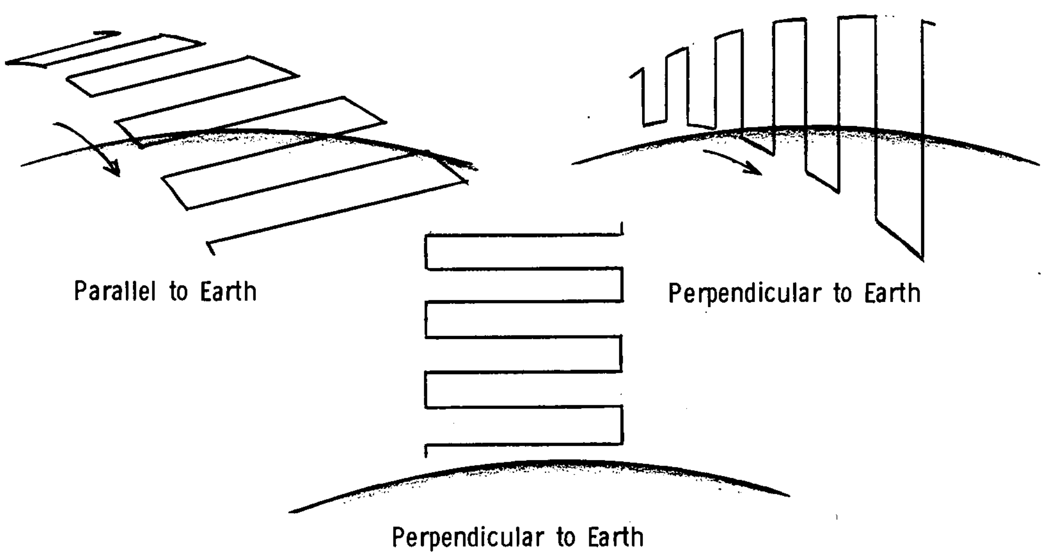
Position

- Latitude
- Longitude
- Altitude

Time

d. Possible Scan Patterns for ASF - Below are sketches of three possible programmed pointing sequences. The orientation of the rasters would depend on particular experimental requirements. The main instrument cluster need not be scanned at all, however.

POSSIBLE SCAN PATTERNS FOR ASF



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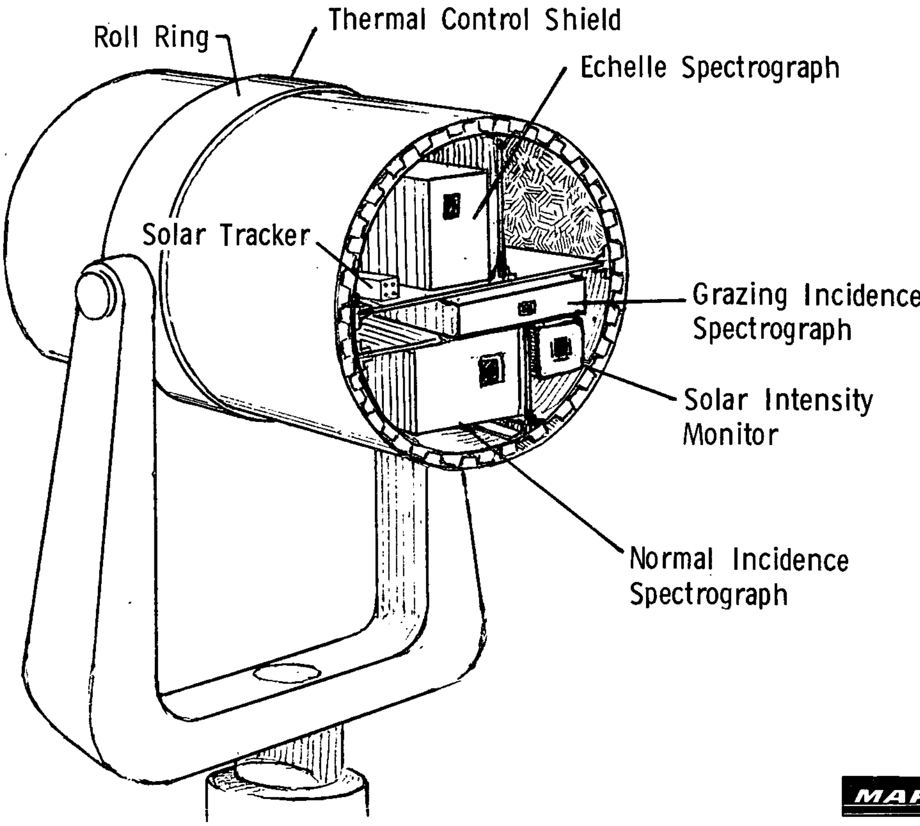
2. Solar Monitor and Gimbal Mount

The solar instruments would be mounted together and boresighted to a common line of sight. A solar tracker automatically acquires the solar disk when it is visible, and the three-axis gimbal would be driven according to selectable programs to scan the solar disk. A thermal control shield surrounding the cluster would protect the instruments from thermal distortion due to the direct solar radiation. The diameter of the canister is determined by the necessity to turn the grazing incidence spectrograph at an angle to boresight the instrument properly with the other solar instruments.

SOLAR MONITOR AND GIMBAL MOUNT



Length - 7 ft
Dia - 4.5 ft
Height - 8 ft
Weight - 600 lb

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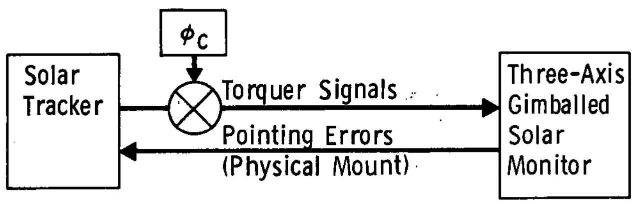
Solar Monitor Pointing and Control - The pointing system for the solar monitor would have the capability of pointing the cluster to within 1 arc min relative to the center of the solar disk. Because the field of view of the high-resolution instruments is a small fraction of the solar disk, to obtain spectra representative of the entire solar disk the mount would be scanned across the disk by offset signals introduced into the control system.

SOLAR MONITOR POINTING AND CONTROL

	Requirement	Capability
Absolute Pointing	--	--
Relative Pointing	6 arc min	1 arc min
Stability	1 arc min	1 arc min

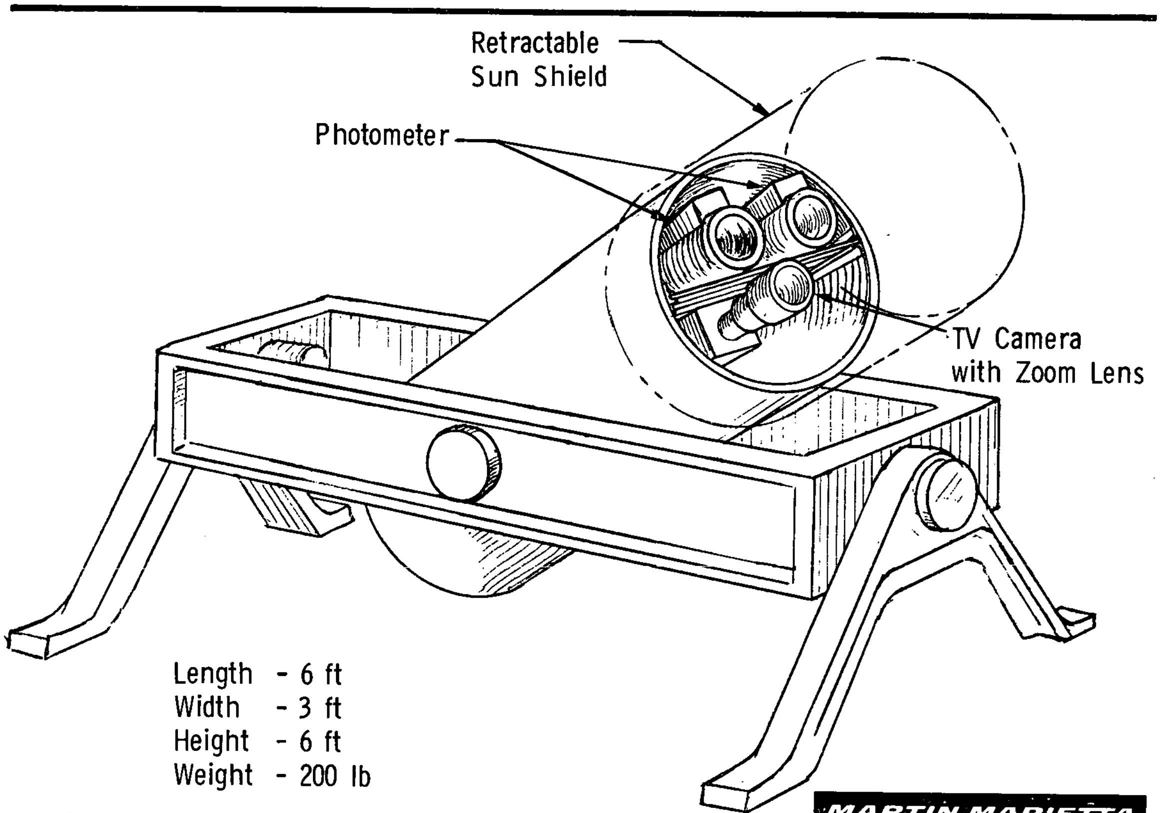


3. Previewer and Gimbal Mount

A separate, indepently pointable mount would be provided for a previewer, which would allow upcoming targets to be observed without interfering with ongoing measurements involving the main instrument cluster, as well as enabling searches to be performed for transient phenomena.

Previewer instruments would be boresighted to a common pointing direction. Two kinds of instruments would be included, a television camera and two filter photometers. The TV camera would provide a wide spectral coverage and a zoom lens for varying the field of view. The photometers would cover several narrow spectral bands, both within and without the visible. Such spectral bands would allow the operator to monitor specific atmospheric emission features, and could be easily tailored to a specific mission. The operator would manually control the pointing, and would have the option of commanding the main instrument cluster to slave to the line of sight of the previewer when a target of interest has been acquired.

PREVIEWER AND GIMBAL MOUNT



Length - 6 ft
Width - 3 ft
Height - 6 ft
Weight - 200 lb

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a. Observational Requirements for Previewer - The primary requirement for a previewer on a board ASF is to extend the spatial and spectral range of the payload specialist. Included on the previewer would be two photometers and a TV camera with zoom lens. The photometers would be used with sensitivity comparable to that found in the main instrument cluster, and would provide "threshold" information for these instruments. The TV camera, in conjunction with the photometers, would identify and track targets of opportunity. This function would be performed by the payload specialist, using a steering lever to point the previewer, while monitoring the display screen. Lastly, the previewer would provide gimbal pointing information to the main instrument cluster. In this way the line of sight of the main instrument cluster could be slaved automatically to the line of sight of the previewer upon command.

OBSERVATIONAL REQUIREMENTS FOR PREVIEWER

Extend Spectral, Spatial Range

Provide "Threshold" Information to Main Instrument Cluster

Identify and Track "Targets of Opportunity"

Provide "Slave" Information to Main Instrument Cluster

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b. Previewer Photometers - Optically the previewer photometers are identical to those on the main instrument cluster. Each of the photometers would have a set of selectable narrow band filters to isolate particular emission lines. Two photometers are used because different detectors are needed to cover the whole spectral range from 1216 to 7000 Å. Wavelength resolution, depending on the choice of filter, could be ∿15 Å, and, to provide meaningful threshold signals, the same range of fields of view would be available as those on the instruments of the main instrument cluster.

PREVIEWER PHOTOMETERS	
Collecting Optics	Off-Axis Paraboloid (152 mm Aperture)
Focal Ratio	~f/3
Wavelengths (Rotating Filter Wheel)	
Photometer No. 1	1216, 1500, 2600, 3100 Å
Photometer No. 2	3371, 3914, 5577, 7000 Å
Wavelength Resolution	~15 Å
Field of View	Selectable 1 arc min to 1 degree

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c. Previewer Pointing and Control - Because the previewer has a relatively wide field of view, its pointing requirements are not as severe as the other instrument clusters and are easily achieved. Necessary pointing information is derived directly from the Shuttle inertial guidance system.

PREVIEWER POINTING AND CONTROL

	Requirement	Capability
Absolute Pointing	20 arc min	15 arc min
Relative Pointing	5 arc min	3 arc min
Stability	3 arc min	1 arc min

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d. Previewer Outputs to Payload Specialist - In addition to the instrument outputs that would be available to the payload specialist, the display of the field on the television picture could be annotated with the location of the main instrument line of sight, the line of sight of the previewer and the nadir position of the Shuttle and its direction. Along with a pictorial presentation, an output of the latitude and longitude of these points would be available in digital form. Other outputs could be the time, the altitude of Shuttle, ground speed and the outputs of the photometer channels.

PREVIEWER OUTPUTS TO PAYLOAD SPECIALIST

Latitude, Longitude of Shuttle Nadir

Latitude, Longitude of Previewer Line of Sight

Latitude, Longitude of Main Instrument Cluster Line of Sight

Time

Altitude

Ground Speed

Photometer Channel Outputs

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3

e. Previewer Performance Summary - The TV camera and zoom lens would extend the spectral range of the payload specialist from 0.3 to 0.8 μm and would provide a field of view from 2 to 22 deg. Enhancement techniques could be used on the TV system that would provide improved imagery to the payload specialist, thus increasing the usefulness of the TV images. The various techniques are three. The first is to select absolute grey level values and assign colors to these levels. This requires a color monitor output with a monochrome TV camera. The second method is to use both a color monitor and color TV camera. The third method is to use intensity filtering techniques whereby the TV monitor would display isophotes which could be selected by the payload specialist.

The photometers used on the previewer would provide a selection of wavelengths ranging from 1216 to 8000 Å with possible extention into the IR. The sensitivity of the photometers would be comparable to those in the main instrument cluster. Selection of the field of view in the range 1 arc min to 1 deg in discrete steps would be available to the payload specialist.

Derotation of the image would be done electronically and automatically with a manual override and control.

PREVIEWER PERFORMANCE SUMMARY

TV Camera and Zoom Lens

- Extended Spectral Range
- Variable Field of View
- Image Enhancement

Photometers

- Selection of Wavelengths
- High Sensitivity
- Variable Field of View

Image Derotation

APPENDIX B--APPROACHES INVESTIGATED AND ABANDONED

This appendix discusses concepts that were considered and abandoned during the study. The significant reasons for dropping the approaches are given.

The scientific objectives of the Atmospheric Science Facility (ASF) were originally divided into primary and secondary categories to aid in determining whether the associated instrument requirements would be included in the ASF design. Several justifiable reasons for this division were presented at the time. However, it was found that by making this decision at the objective level it became necessary to exercise undue effort qualifying particular experiments that were perfectly feasible, but fell within a "secondary" objective category. Since one aim of the objectives study was to establish design requirements that would perform a wide variety of experiments, the focus of attention was shifted from general objectives to specific experiments, where careful scrutiny of detailed and sometimes unusual design requirements could be effectively applied.

A module was considered for ASF that would be separable from the Shuttle and capable of gathering data from an independent orbit. Such an approach would be more expensive because the support module would have to provide its own life support, electric power, and other subsystems, and would lose commonality with modules used for other Shuttle payloads. Because the same subsystems must be carried by the support module, the problems of contamination in the vicinity of the Shuttle are not eliminated, but are merely transferred from the design of the Shuttle to the design of the support module. The support services such as communications and power obtainable from the Shuttle are lost and crew safety is reduced. No need has been identified for gathering data beyond a time that is compatible with a Shuttle sortie mission. Finally, the remote manipulator arms on the Shuttle have only a modest capability for attaching to a tumbling object; there is the possibility that the detached ASF would be impossible to reacquire if it started tumbling.

The initial phase of the study was striving for a complement of general-purpose instruments that would satisfy most of the requirements of the scientific community. However, as the study progressed, it was found that it is often necessary to compromise requirements if several experiments are to be performed by one instrument, and if flexibility and the ability to perform several experiments simultaneously are lost. Because it is difficult to predict the instrumentation requirements several years in advance, the most flexible approach adopted was to allow room in the instrument clusters for inclusion of special-purpose instruments to supplement the general-purpose complement.

One of the original concepts investigated for ASF was a single, large aperture, platinum collecting mirror that would serve as the primary mirror for the entire spectral range from the XUV into the infrared. Various spectrometers, radiometers, and other instrumentation would be placed at an off-axis prime focus, and beam splitters and/or dichroics would be used to make simultaneous observations. The large aperture mirror would result in a large and costly system that would permit little flexibility in selecting fields of view and other instrument parameters, and would be less flexible to modify at later periods in the program when scientific requirements and different instrumentation techniques would be adopted. Furthermore, the needs for observation of extended atmospheric sources can be satisfied by smaller aperture collecting optics. A cluster of separate instruments allows each design to be optimized for its wavelength range and permits the cluster to be flown, repaired, or calibrated in a partially complete state of assembly, if program operations make this type of operation desirable.

Use of the main Shuttle computer for all ASF data acquisition and processing operations was rejected in favor of a separate system dedicated to ASF instrument processing. Checkout of the ASF module is much simpler if an autonomous system is available rather than having to rely on a system that may not be available to the preflight checkout crew when desired. Interface problems become simpler if the data processing system is totally dedicated to the instruments. Limitations on the memory or computation capacity may arise if the Shuttle computer is used, and the flexibility and future growth of the ASF are enhanced by a separate system.

The mid-range spectrometer design was originally of the Ebert-Fastie design but detailed ray trace calculations showed that spherical aberation would increase the image size with a sacrifice of spectral resolution. At the price of somewhat greater instrument complexity the preliminary design shifted to the Czerny-Turner configuration.

A single entrance slit and a collecting mirror were included in the original design of the XUV spectrometer. Achieving a high optical throughput is the primary design consideration in view of the low flux levels to be observed. The reflectivity of the collecting mirror in the XUV is low and the field-of-view reduction that it makes possible is not part of the currently defined scientific requirements. The collecting optics were therefore dropped from the design. Furthermore, substitution of an entrance grille pattern for the slit gives a much higher instrument throughput.

The scientific requirements state that the high resolution solar spectra must be representative of the light emanating from the entire solar disk, rather than a restricted region of the disk. A diffusing surface was originally included in the optical layout of the instruments at a considerable reduction in instrument efficiency. The diffusing surface was removed when it was determined that the same effect could be obtained by scanning the slit across the solar image during the time required for one exposure, thereby building up a record of the total disk radiation.

Photographic film was investigated as the detector for the high spectral resolution XUV solar line profile spectrometers. Film has the advantages of good linear resolution and the ability to record a large number of resolution elements simultaneously. Electronic detectors have better dynamic range, linearity, accuracy, and are more convenient to handle. If coverage of a limited portion of the spectral range at one exposure and physically larger and heavier instruments can be accepted, a more accurate and convenient data handling procedure results from use of the more modern electronic detectors using channel electron multiplier plates. Depending on the experimental requirements, either of the two detection schemes could be used.

The original concept for determing the ASF orbital attitude was to use horizon sensors. However, it is necessary to use four sensors pointing at right angles to achieve the required accuracy, which places a visibility requirement on the instrument platform that it may not always be able to satisfy. The 3 arc min accuracy requirement is only marginally achieved with horizon sensors, and no pointing information is given for the location of ground targets. Use of the Shuttle inertial system is complicated by the mechanical tolerances, which will result in loss of alignment between the instrument cluster in the payload bay and the Shuttle inertial system in the forward cabin. The adopted ASF system uses a rate-stabilized gyro inertial platform on the instrument cluster that is periodically updated with star tracker sightings to determine ASF attitude, and obtains the position of the nadir point from the Shuttle navigation system. Adequate accuracy for possibly more stringent future requirements would be available, as well.

The contamination problem is a topic of concern to any manned space optical instrument facility, but with the present state of knowledge, it is impossible to come to any meaningful conclusions if one seeks to analyze the contamination problem for ASF onboard Shuttle. At this stage in the program the effluents emitted by the Shuttle could be specified, and the allowable degradation in instrument performance could perhaps be specified. However, it is impossible to predict the effects on an instrument of a given contaminant level with current knowledge. The contamination effects of the Skylab flights need to be analyzed before a significant evaluation of the Shuttle contamination problem can be performed.